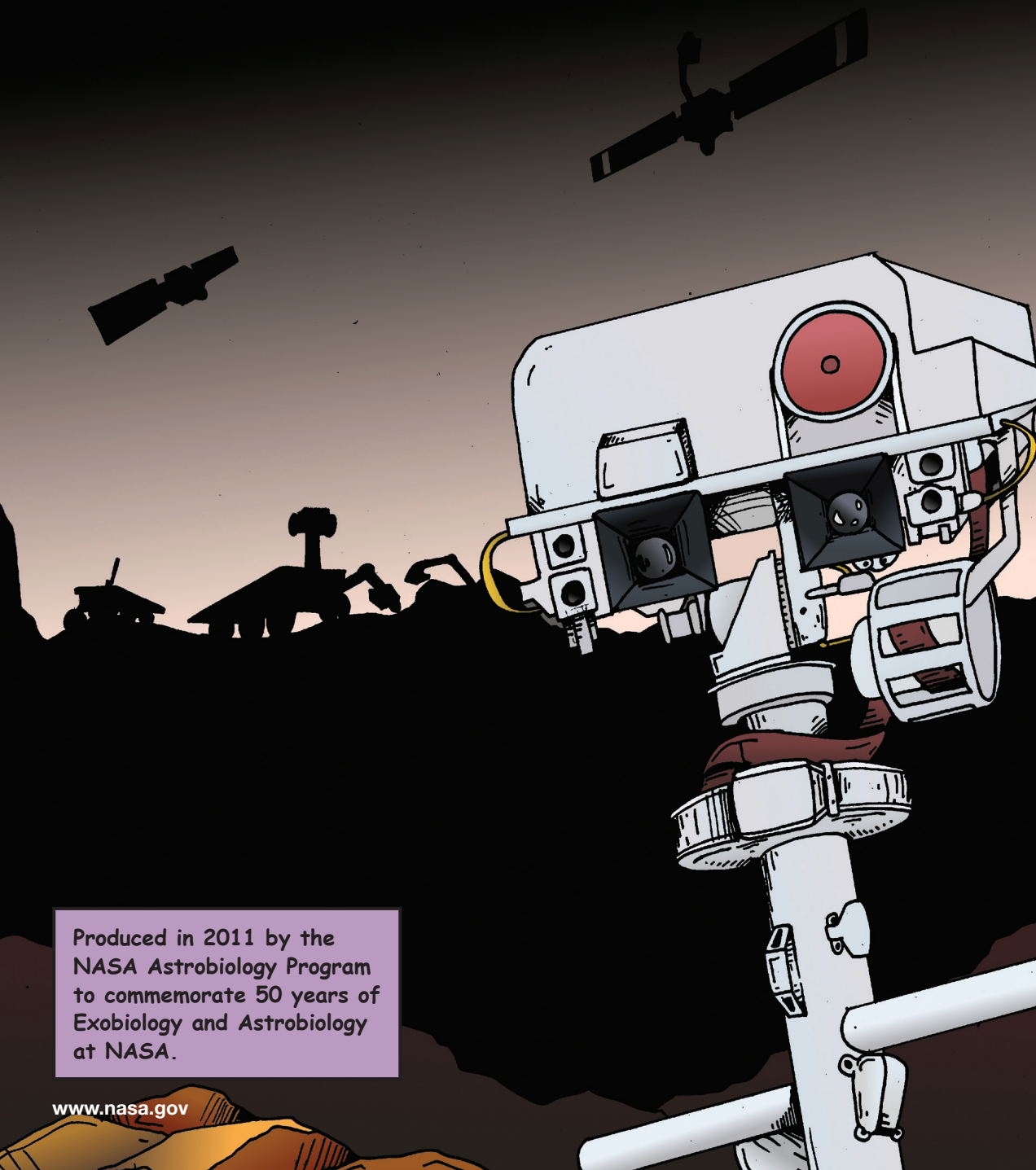
National Aeronautics and Space Administration

Issue #2

ASTROBIOLOGY

The Story of our Search for Life in the Universe



Produced in 2011 by the NASA Astrobiology Program to commemorate 50 years of Exobiology and Astrobiology at NASA.

www.nasa.gov

Astrobiology

A History of Exobiology and Astrobiology at NASA

This is the story of life in the Universe—or at least the story as we know it so far. As scientists, we strive to understand the environment in which we live and how life relates to this environment. As astrobiologists, we study an environment that includes not just the Earth, but the entire Universe in which we live.

The year 2010 marked 50 years of Exobiology and Astrobiology research at the National Aeronautics and Space Administration (NASA). To celebrate, the Astrobiology Program commissioned this graphic history. It tells the story of some of the most important people and events that have shaped the science of Exobiology and Astrobiology. At only 50 years old, this field is relatively young. However, as you will see, the questions that astrobiologists are trying to answer are as old as humankind.

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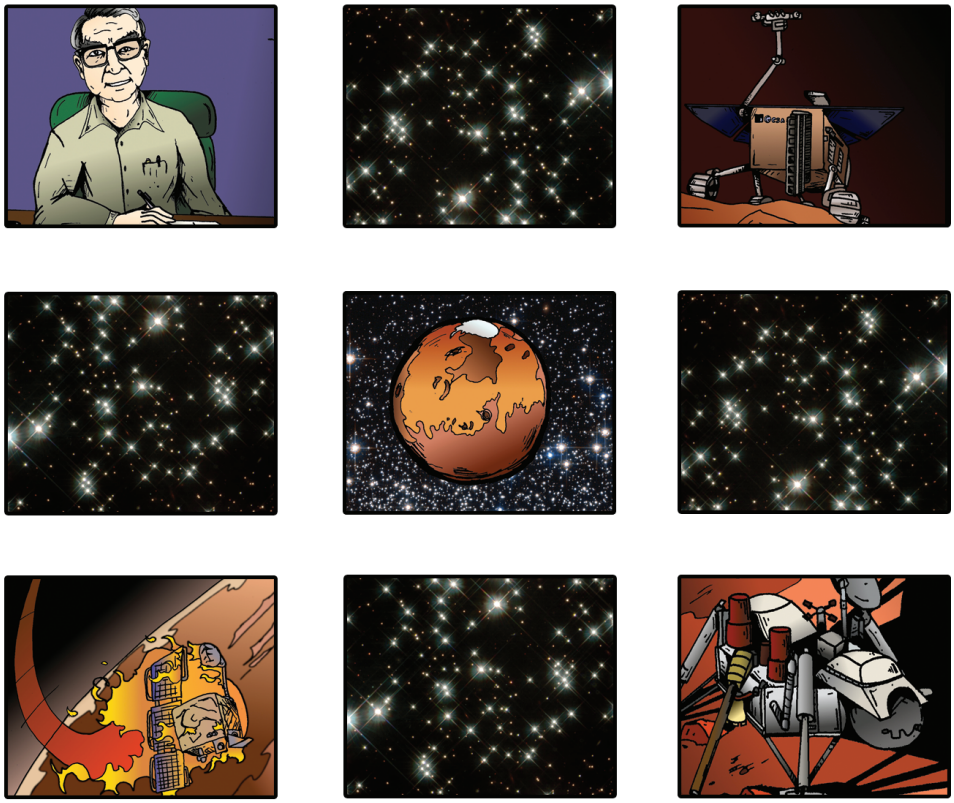
Issue #2—Missions to Mars

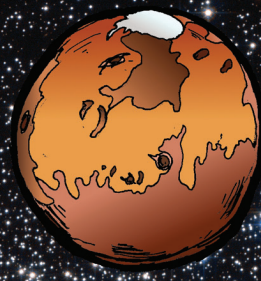


The year 2010 marked the 50th anniversary of NASA's Exobiology Program, established in 1960 and expanded into a broader Astrobiology Program in the 1990s. To commemorate the past half century of research, we are telling the story of how this field developed and how the search for life elsewhere became a key component of NASA's science strategy for exploring space. This issue is the second in what we intend to be a series of graphic history books. Though not comprehensive, the series has been conceived to highlight key moments and key people in the field as it explains how Astrobiology came to be.

-Linda Billings, Editor

Astrobiology, the study of life's origin, evolution, distribution and future in the Universe, has been a key part of NASA's research since the agency began. In 1960, NASA established an Exobiology Program. Entering the 'boom days' of space exploration, NASA began to launch numerous missions into orbit and beyond. Astrobiology was ready for the ride.

Issue 2—Missions to Mars.



NASA has explored many places in the Solar System, but in this issue we're going to focus on one of the most important destinations for Exobiology and Astrobiology science—**Mars**.

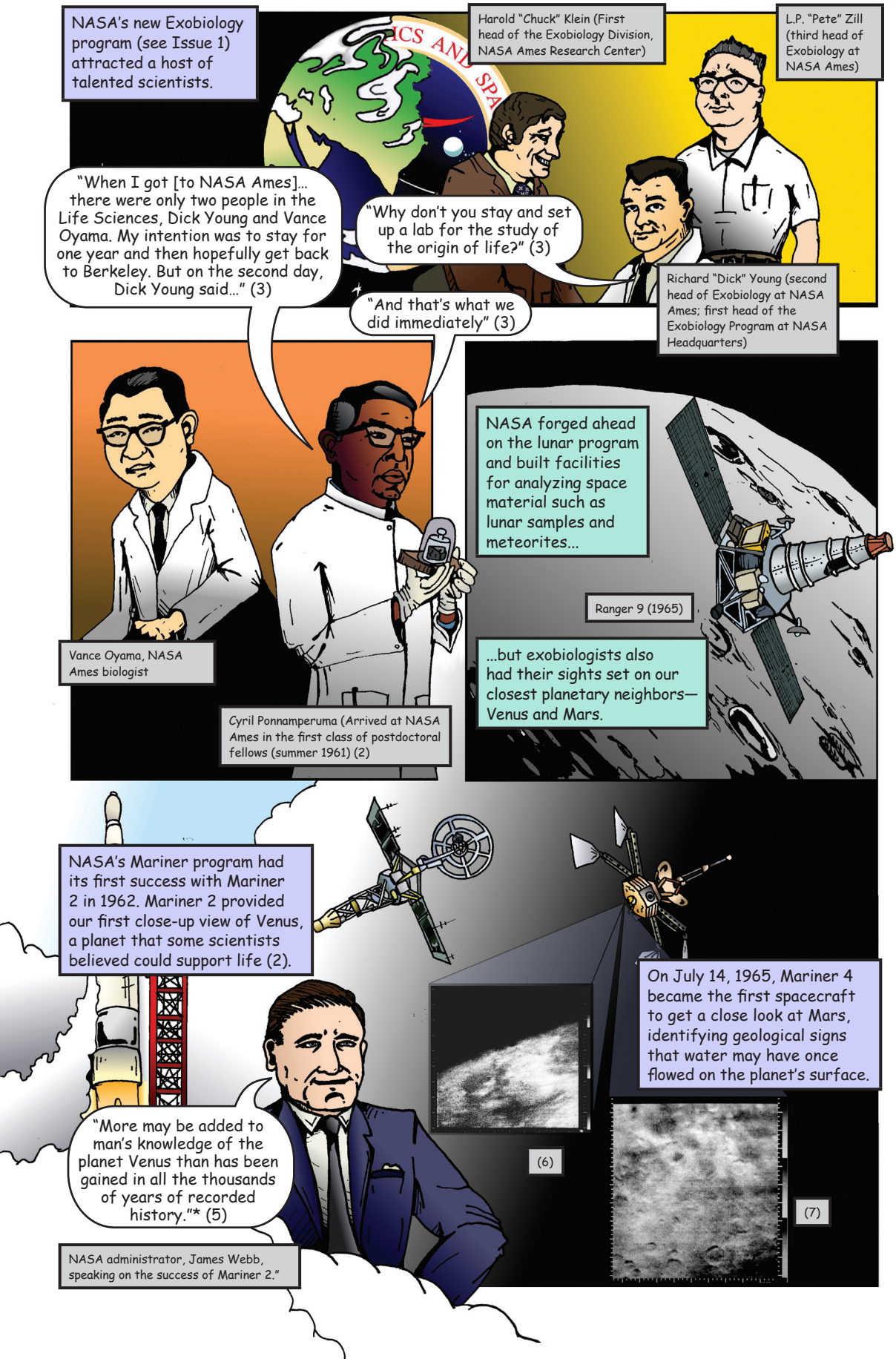
Mars was a complete mystery when the space age began, but exploration has revealed that Mars might have been more Earth-like in its past. However, many questions still remain. What was ancient Mars like? Was there ever liquid water on the surface of Mars? Long ago, could Mars have supported life as we know it?

The history of missions to Mars is full of struggle and triumph. Mars is a dangerous and difficult planet to visit. The extreme environment of the planet includes frigid temperatures, damaging dust storms, low gravity and a thin atmosphere. Many missions to Mars have ended in failure, but the missions that were successful have provided fascinating evidence of Mars' potential habitability.

The year 2010 marked half a century of Exobiology and Astrobiology research at NASA. In 2011, we will celebrate a new era of Astrobiology research in Mars exploration with the launch of NASA's most ambitious Mars mission to date—the **Mars Science Laboratory**.

But first... let's take a closer look at Mars' role in the history of Exobiology and Astrobiology.

Background Image: Globular Cluster (1)


NASA's new Exobiology program (see Issue 1) attracted a host of talented scientists.
Harold "Chuck" Klein (First head of the Exobiology Division, NASA Ames Research Center)
L.P. "Pete" Zill (third head of Exobiology at NASA Ames)
"Why don't you stay and set up a lab for the study of the origin of life?" (3)
Richard "Dick" Young (second head of Exobiology at NASA Ames; first head of the Exobiology Program at NASA Headquarters)
"When I got [to NASA Ames]... there were only two people in the Life Sciences, Dick Young and Vance Oyama. My intention was to stay for one year and then hopefully get back to Berkeley. But on the second day, Dick Young said..." (3)
"And that's what we did immediately" (3)
Vance Oyama, NASA Ames biologist
Cyril Ponnamperuma (Arrived at NASA Ames in the first class of postdoctoral fellows (summer 1961) (2)
NASA forged ahead on the lunar program and built facilities for analyzing space material such as lunar samples and meteorites...
Ranger 9 (1965)
...but exobiologists also had their sights set on our closest planetary neighbors—Venus and Mars.
NASA's Mariner program had its first success with Mariner 2 in 1962. Mariner 2 provided our first close-up view of Venus, a planet that some scientists believed could support life (2).
On July 14, 1965, Mariner 4 became the first spacecraft to get a close look at Mars, identifying geological signs that water may have once flowed on the planet's surface.
(6)
(7)
"More may be added to man's knowledge of the planet Venus than has been gained in all the thousands of years of recorded history."* (5)
NASA administrator, James Webb, speaking on the success of Mariner 2."

Mariner 5 (1967) turned back to Venus. Observations of its harsh environment by Mariners 2 and 5 helped solidify the idea that Mars was a better place to hunt for life.

Our vision of Mars began to evolve with Mariners 6 and 7 (1969). These two spacecraft mapped 20% of the martian surface, providing detailed images of many of the planet's unique features.

(8)

(9)

(10)

Mariner 9 (1971) was the first spacecraft to enter orbit around another planet. It mapped 80% of Mars. The mission truly unveiled Mars, showing fascinating details of the planet's geological history including volcanoes, canyons, craters and riverbeds. Mariner 9 returned the first images of landmarks such as *Valles Marineris*, the vast canyon named in the spacecraft's honor.

(11)

(12)

The program's final mission, Mariner 10 (1973), didn't visit Mars, but it demonstrated techniques that would be used in many space missions to follow. Mariner 10 was the first spacecraft to visit multiple planets, and the first to use the *gravitational assist* of one planet (Venus) to build up enough speed to visit a second (Mercury).

(13)

The Soviet Union had also set its sights on Mars. The Mars 2 (1971), Mars 3 (1971), and Mars 5 (1973) missions directed spacecraft into Mars orbit. Although each suffered difficulties, they produced data on the surface and atmospheric conditions of the planet (15).

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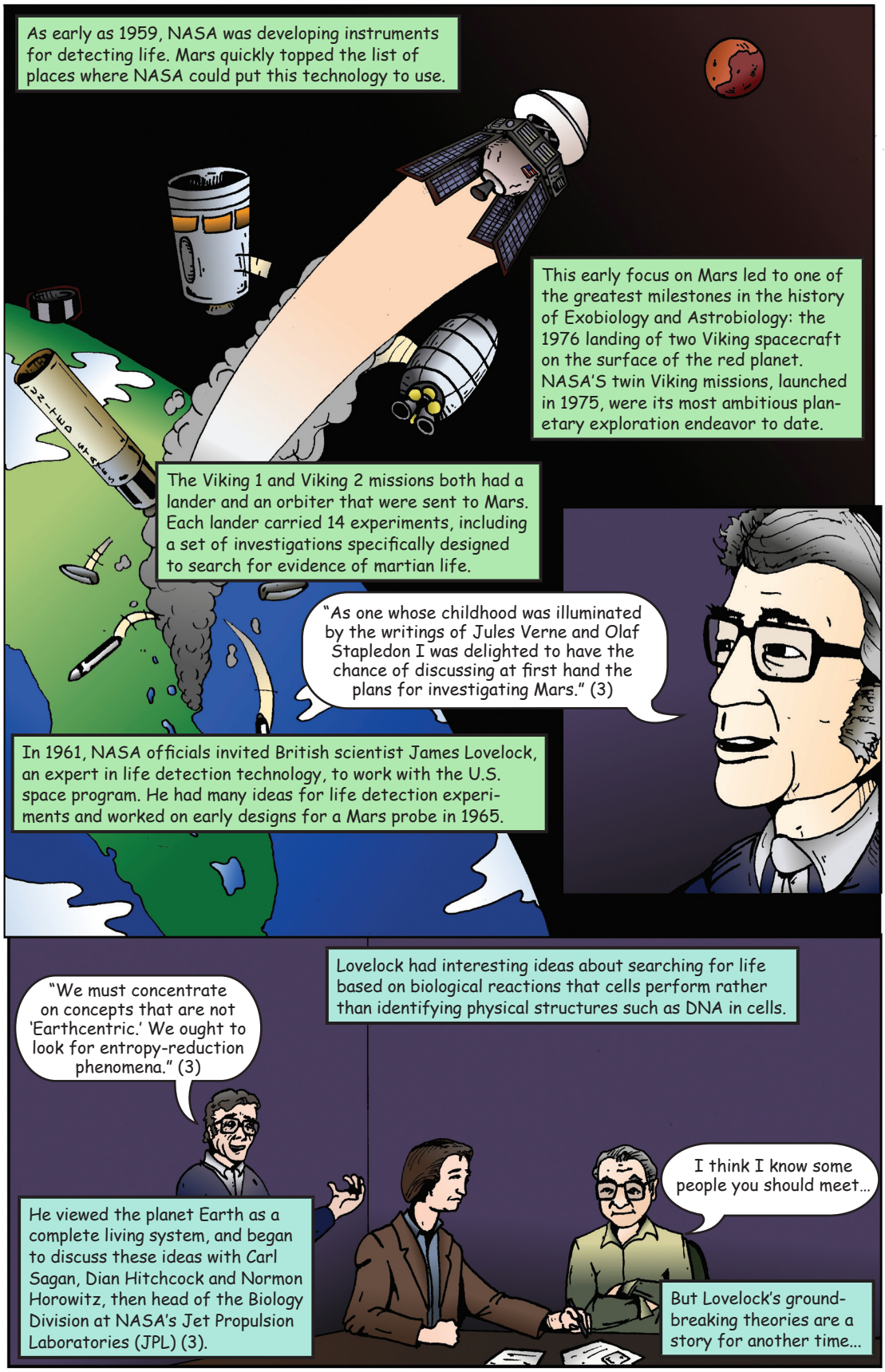
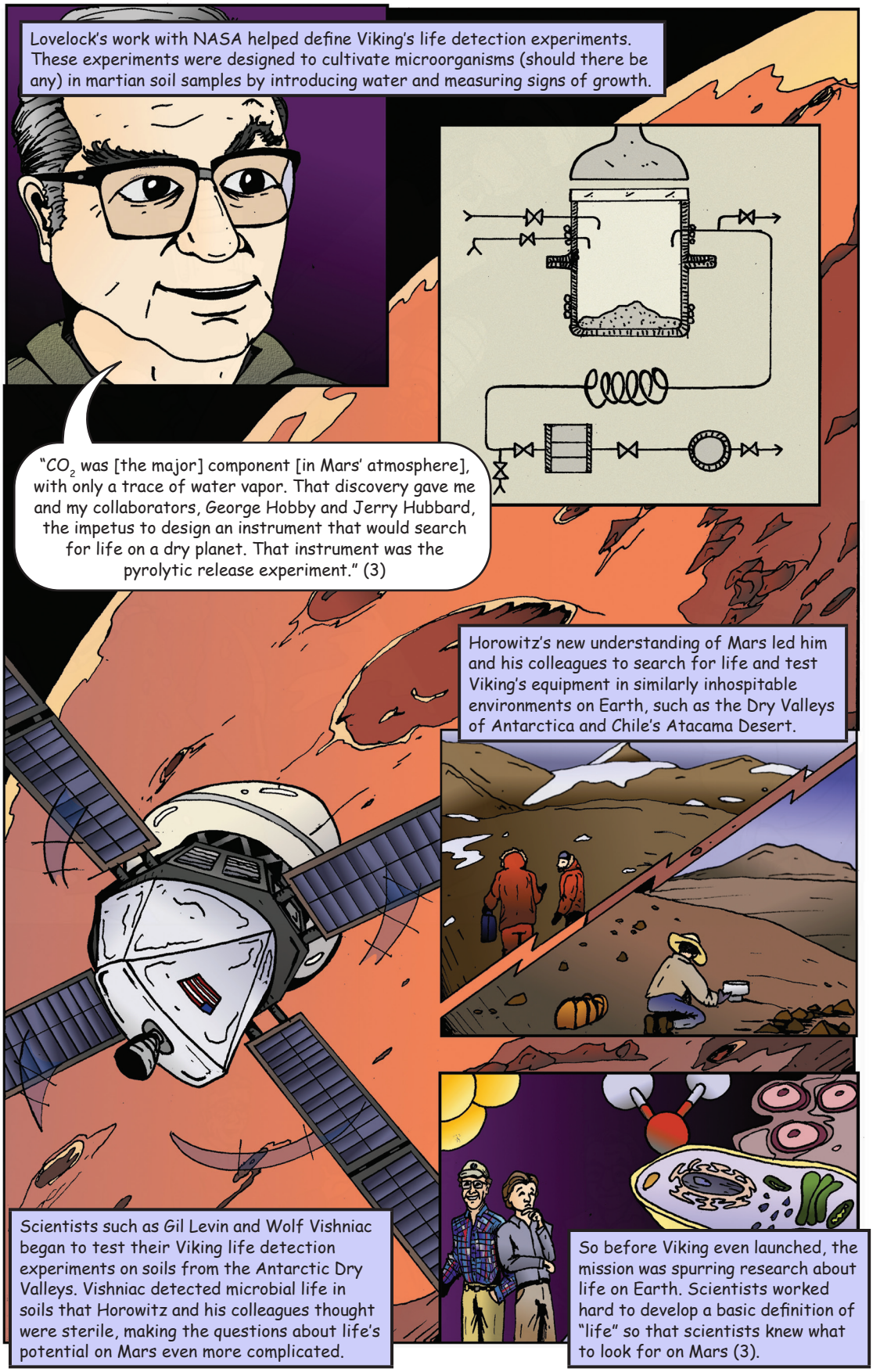
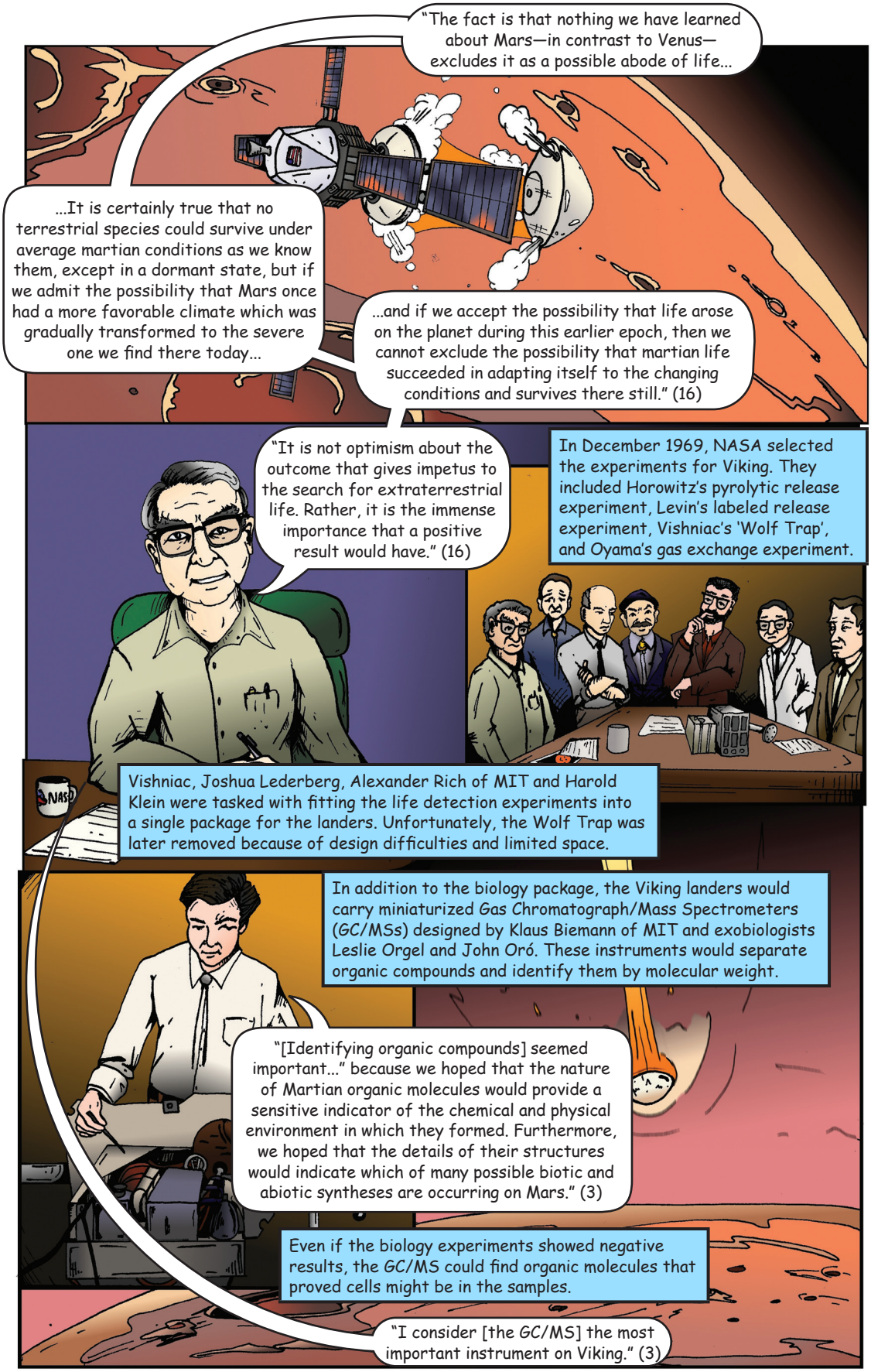

As early as 1959, NASA was developing instruments for detecting life. Mars quickly topped the list of places where NASA could put this technology to use.
This early focus on Mars led to one of the greatest milestones in the history of Exobiology and Astrobiology: the 1976 landing of two Viking spacecraft on the surface of the red planet. NASA'S twin Viking missions, launched in 1975, were its most ambitious planetary exploration endeavor to date.
The Viking 1 and Viking 2 missions both had a lander and an orbiter that were sent to Mars. Each lander carried 14 experiments, including a set of investigations specifically designed to search for evidence of martian life.
"As one whose childhood was illuminated by the writings of Jules Verne and Olaf Stapledon I was delighted to have the chance of discussing at first hand the plans for investigating Mars." (3)
In 1961, NASA officials invited British scientist James Lovelock, an expert in life detection technology, to work with the U.S. space program. He had many ideas for life detection experiments and worked on early designs for a Mars probe in 1965.
Lovelock had interesting ideas about searching for life based on biological reactions that cells perform rather than identifying physical structures such as DNA in cells.
"We must concentrate on concepts that are not 'Earthcentric.' We ought to look for entropy-reduction phenomena." (3)
He viewed the planet Earth as a complete living system, and began to discuss these ideas with Carl Sagan, Dian Hitchcock and Normon Horowitz, then head of the Biology Division at NASA's Jet Propulsion Laboratories (JPL) (3).
I think I know some people you should meet...
But Lovelock's groundbreaking theories are a story for another time...


Lovelock's work with NASA helped define Viking's life detection experiments. These experiments were designed to cultivate microorganisms (should there be any) in martian soil samples by introducing water and measuring signs of growth.
"CO_2 was [the major] component [in Mars' atmosphere], with only a trace of water vapor. That discovery gave me and my collaborators, George Hobby and Jerry Hubbard, the impetus to design an instrument that would search for life on a dry planet. That instrument was the pyrolytic release experiment." (3)
Horowitz's new understanding of Mars led him and his colleagues to search for life and test Viking's equipment in similarly inhospitable environments on Earth, such as the Dry Valleys of Antarctica and Chile's Atacama Desert.
Scientists such as Gil Levin and Wolf Vishniac began to test their Viking life detection experiments on soils from the Antarctic Dry Valleys. Vishniac detected microbial life in soils that Horowitz and his colleagues thought were sterile, making the questions about life's potential on Mars even more complicated.
So before Viking even launched, the mission was spurring research about life on Earth. Scientists worked hard to develop a basic definition of "life" so that scientists knew what to look for on Mars (3).


"The fact is that nothing we have learned about Mars—in contrast to Venus—excludes it as a possible abode of life...
...It is certainly true that no terrestrial species could survive under average martian conditions as we know them, except in a dormant state, but if we admit the possibility that Mars once had a more favorable climate which was gradually transformed to the severe one we find there today...
...and if we accept the possibility that life arose on the planet during this earlier epoch, then we cannot exclude the possibility that martian life succeeded in adapting itself to the changing conditions and survives there still." (16)
"It is not optimism about the outcome that gives impetus to the search for extraterrestrial life. Rather, it is the immense importance that a positive result would have." (16)
In December 1969, NASA selected the experiments for Viking. They included Horowitz's pyrolytic release experiment, Levin's labeled release experiment, Vishniac's 'Wolf Trap', and Oyama's gas exchange experiment.
Vishniac, Joshua Lederberg, Alexander Rich of MIT and Harold Klein were tasked with fitting the life detection experiments into a single package for the landers. Unfortunately, the Wolf Trap was later removed because of design difficulties and limited space.
In addition to the biology package, the Viking landers would carry miniaturized Gas Chromatograph/Mass Spectrometers (GC/MSs) designed by Klaus Biemann of MIT and exobiologists Leslie Orgel and John Oró. These instruments would separate organic compounds and identify them by molecular weight.
"[Identifying organic compounds] seemed important..." because we hoped that the nature of Martian organic molecules would provide a sensitive indicator of the chemical and physical environment in which they formed. Furthermore, we hoped that the details of their structures would indicate which of many possible biotic and abiotic syntheses are occurring on Mars." (3)
Even if the biology experiments showed negative results, the GC/MS could find organic molecules that proved cells might be in the samples.
"I consider [the GC/MS] the most important instrument on Viking." (3)

On July 20, 1976—seven years after the Apollo 11 lunar landing—the Viking 1 lander touched down on the flat, martian plain of *Chryse Planitia*.

To prevent contamination of Mars, the Viking Landers were assembled in a special clean room, baked in dry heat to kill any microorganisms and kept in isolation until landing on Mars.

Cameras on the lander revealed a surface far different—and far more familiar—than that of the Moon. On July 28, the lander's mechanical arm dug a trench about five centimeters deep and scooped samples into the instruments and GC/MS.

On September 3rd, Viking 2 landed halfway around the planet on the plain of *Utopia*.

The world watched as results began to pour in from the Viking experiments.

All of the biology experiments showed evidence of activity in the samples after the very first test. The pyrolytic release experiment gave one reading consistent with photosynthesis occurring, but the initial result couldn't be repeated. The gas release experiment showed oxygen released from the Mars soil—but many scientists thought the results looked more like a chemical reaction than a biological reaction.

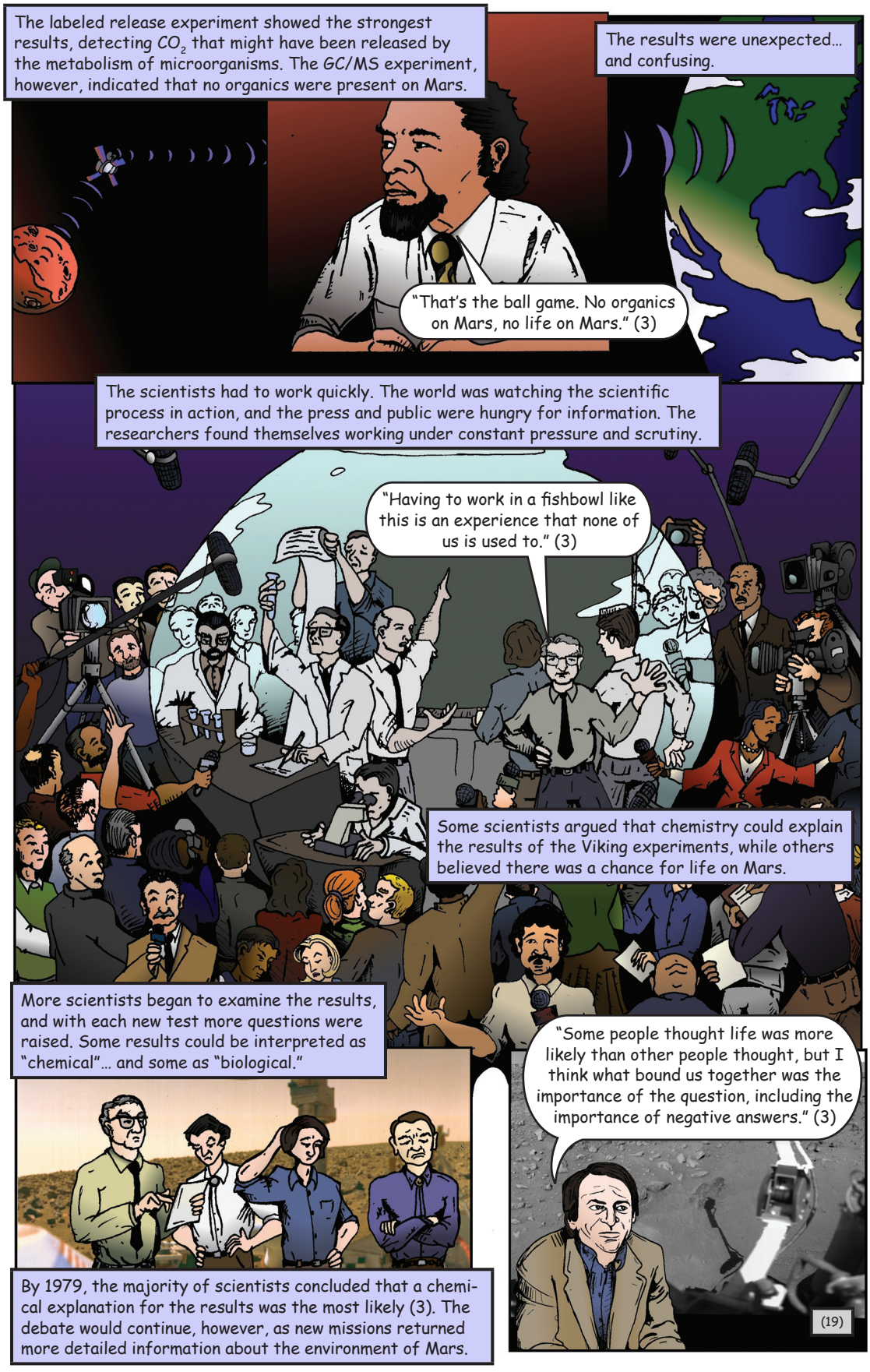
"This is just an incredible scene..." (17)

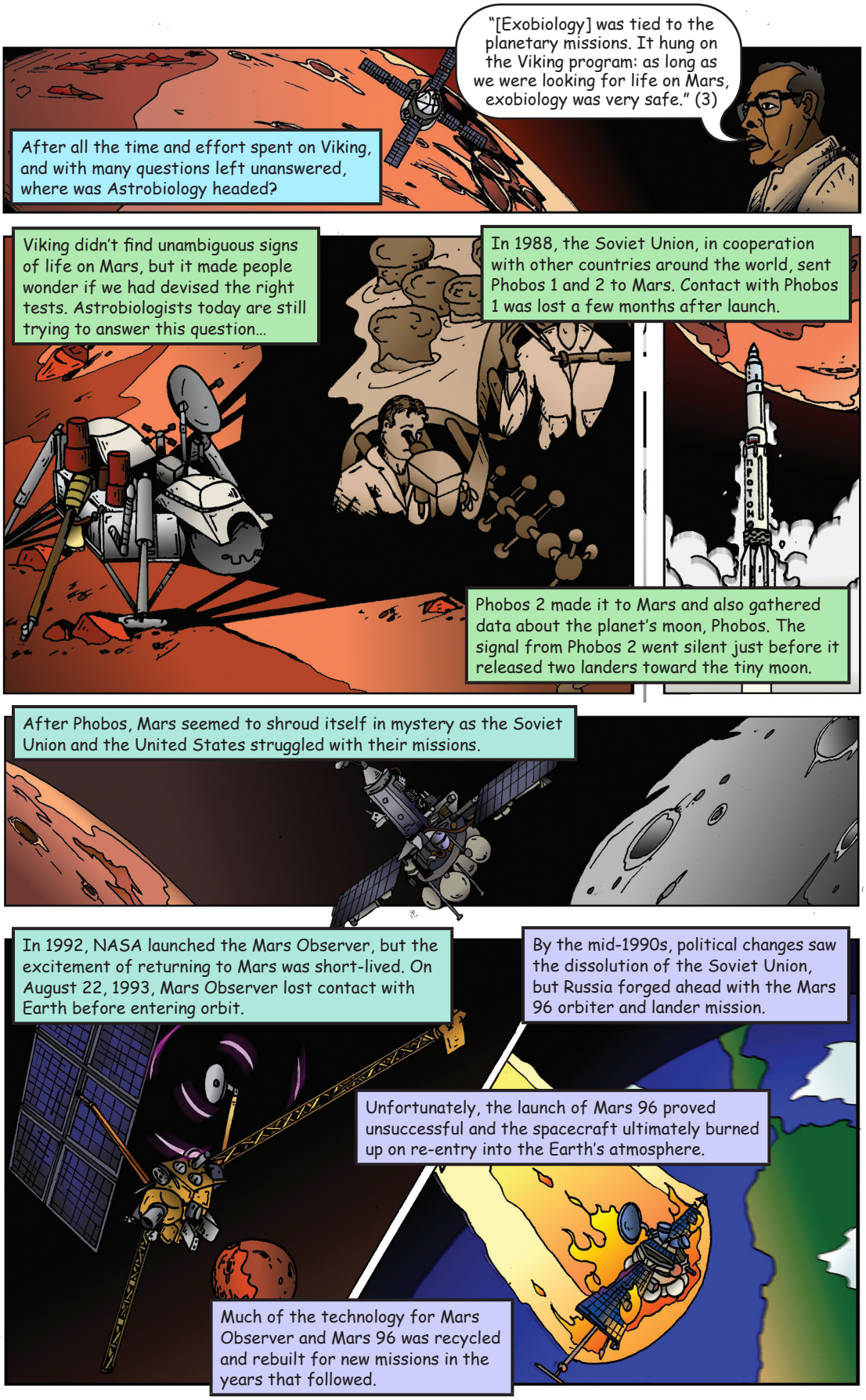
"A new reality was created. Mars became a place. It went from a word, an abstract thought, to a real place." (3)

(18)

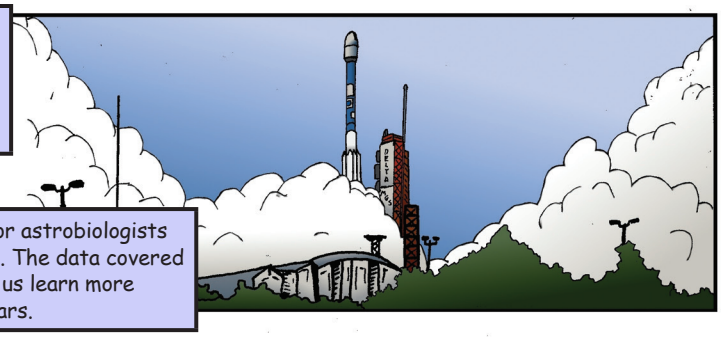
Thomas Mutch, head of the Viking surface photography team.

Gerald Soffen, Viking Project Manager


The labeled release experiment showed the strongest results, detecting CO_2 that might have been released by the metabolism of microorganisms. The GC/MS experiment, however, indicated that no organics were present on Mars.
The results were unexpected… and confusing.
"That's the ball game. No organics on Mars, no life on Mars." (3)
The scientists had to work quickly. The world was watching the scientific process in action, and the press and public were hungry for information. The researchers found themselves working under constant pressure and scrutiny.
"Having to work in a fishbowl like this is an experience that none of us is used to." (3)
Some scientists argued that chemistry could explain the results of the Viking experiments, while others believed there was a chance for life on Mars.
More scientists began to examine the results, and with each new test more questions were raised. Some results could be interpreted as "chemical"… and some as "biological."
By 1979, the majority of scientists concluded that a chemical explanation for the results was the most likely (3). The debate would continue, however, as new missions returned more detailed information about the environment of Mars.
"Some people thought life was more likely than other people thought, but I think what bound us together was the importance of the question, including the importance of negative answers." (3)

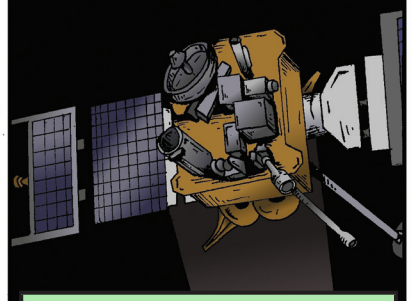

"[Exobiology] was tied to the planetary missions. It hung on the Viking program: as long as we were looking for life on Mars, exobiology was very safe." (3)
After all the time and effort spent on Viking, and with many questions left unanswered, where was Astrobiology headed?
Viking didn't find unambiguous signs of life on Mars, but it made people wonder if we had devised the right tests. Astrobiologists today are still trying to answer this question...
In 1988, the Soviet Union, in cooperation with other countries around the world, sent Phobos 1 and 2 to Mars. Contact with Phobos 1 was lost a few months after launch.
PROTON
Phobos 2 made it to Mars and also gathered data about the planet's moon, Phobos. The signal from Phobos 2 went silent just before it released two landers toward the tiny moon.
After Phobos, Mars seemed to shroud itself in mystery as the Soviet Union and the United States struggled with their missions.
In 1992, NASA launched the Mars Observer, but the excitement of returning to Mars was short-lived. On August 22, 1993, Mars Observer lost contact with Earth before entering orbit.
By the mid-1990s, political changes saw the dissolution of the Soviet Union, but Russia forged ahead with the Mars 96 orbiter and lander mission.
Unfortunately, the launch of Mars 96 proved unsuccessful and the spacecraft ultimately burned up on re-entry into the Earth's atmosphere.
Much of the technology for Mars Observer and Mars 96 was recycled and rebuilt for new missions in the years that followed.

On November 7, 1996, NASA launched the Mars Global Surveyor (MGS). Some of the instruments that MGS carried were originally designed for the failed Mars Observer.



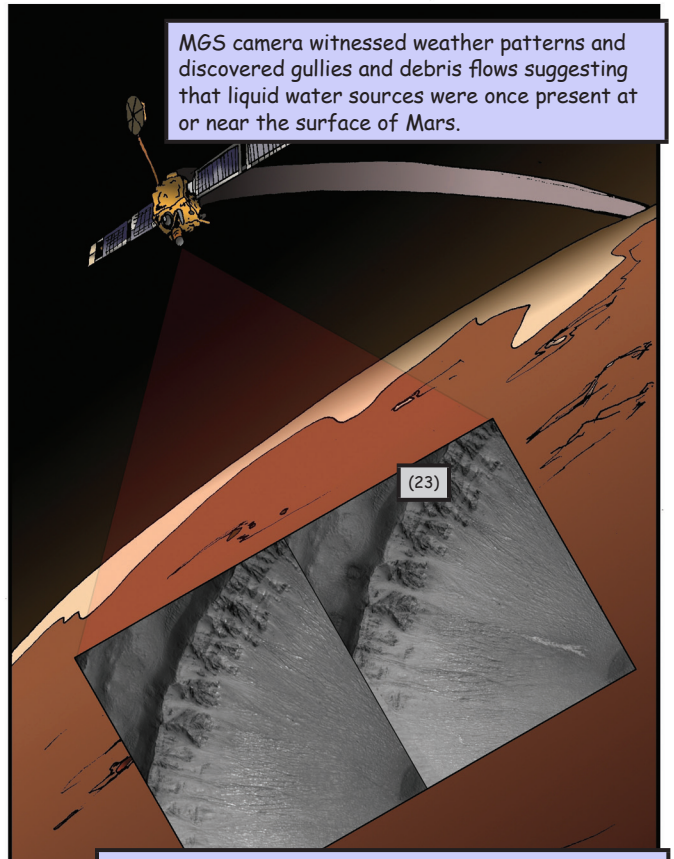
MGS returned essential information for astrobiologists studying the potential for life on Mars. The data covered the entire martian surface and helped us learn more about the role of water and dust on Mars.

Viking highlighted the fact that we didn't yet know enough about life on Earth to search for signs of life on another planet. Scientists decided it would be better to study the environment of Mars, both past and present, in order to understand if the planet could have been a habitable environment for life as we know it.



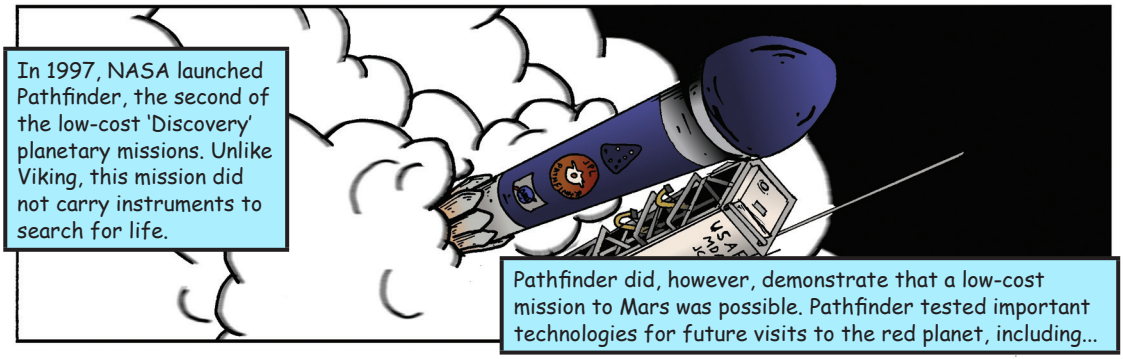
A key requirement for life on Earth is liquid water—so the search for life in the Solar System became focused on searching for environments where liquid water is (or was) present.

MGS camera witnessed weather patterns and discovered gullies and debris flows suggesting that liquid water sources were once present at or near the surface of Mars.

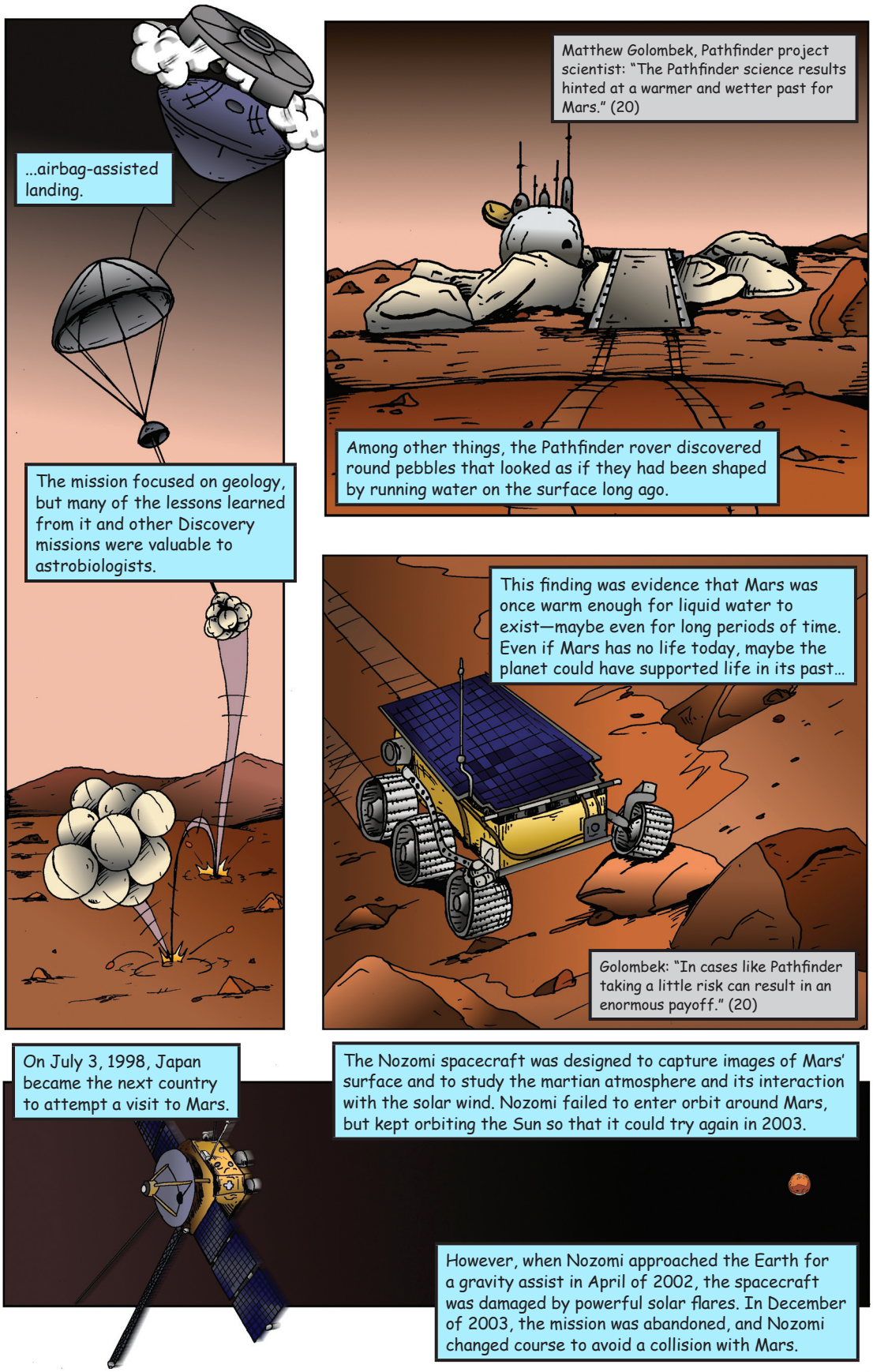


For instance, MGS images from 2004 and 2005 were used to identify the formation of new gully deposits in the *Centauri Montes* region. These deposits look like they could have been made by running water... meaning **liquid** water might still flow on Mars today (22).

In 1997, NASA launched Pathfinder, the second of the low-cost 'Discovery' planetary missions. Unlike Viking, this mission did not carry instruments to search for life.

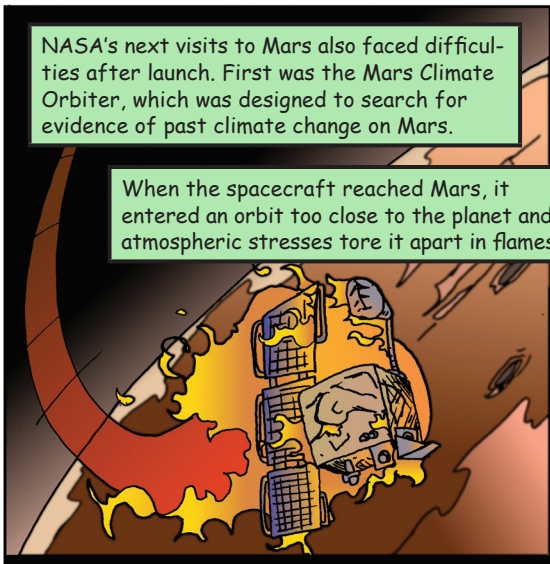


Pathfinder did, however, demonstrate that a low-cost mission to Mars was possible. Pathfinder tested important technologies for future visits to the red planet, including...


...airbag-assisted landing.
The mission focused on geology, but many of the lessons learned from it and other Discovery missions were valuable to astrobiologists.
Matthew Golombek, Pathfinder project scientist: "The Pathfinder science results hinted at a warmer and wetter past for Mars." (20)
Among other things, the Pathfinder rover discovered round pebbles that looked as if they had been shaped by running water on the surface long ago.
This finding was evidence that Mars was once warm enough for liquid water to exist—maybe even for long periods of time. Even if Mars has no life today, maybe the planet could have supported life in its past...
Golombek: "In cases like Pathfinder taking a little risk can result in an enormous payoff." (20)
On July 3, 1998, Japan became the next country to attempt a visit to Mars.
The Nozomi spacecraft was designed to capture images of Mars' surface and to study the martian atmosphere and its interaction with the solar wind. Nozomi failed to enter orbit around Mars, but kept orbiting the Sun so that it could try again in 2003.
However, when Nozomi approached the Earth for a gravity assist in April of 2002, the spacecraft was damaged by powerful solar flares. In December of 2003, the mission was abandoned, and Nozomi changed course to avoid a collision with Mars.

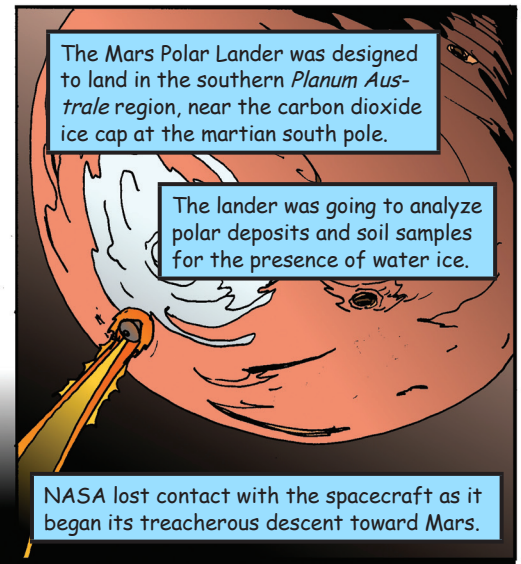
NASA's next visits to Mars also faced difficulties after launch. First was the Mars Climate Orbiter, which was designed to search for evidence of past climate change on Mars.

When the spacecraft reached Mars, it entered an orbit too close to the planet and atmospheric stresses tore it apart in flames.



The Mars Polar Lander was designed to land in the southern *Planum Australe* region, near the carbon dioxide ice cap at the martian south pole.

The lander was going to analyze polar deposits and soil samples for the presence of water ice.

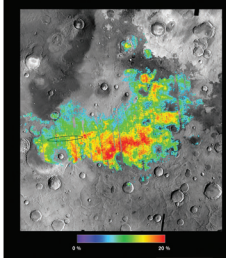


NASA lost contact with the spacecraft as it began its treacherous descent toward Mars.

On April 7, 2001, NASA made a successful return to Mars with the 2001 Mars Odyssey mission. The spacecraft reached Mars on October 24 and has continued to return data ever since.

Odyssey has mapped the chemical elements and minerals that make up the martian surface, providing essential information about the martian environment and the potential for past or present life on the planet.

Odyssey's maps of hydrogen in particular helped scientists discover vast amounts of water ice just beneath the surface at Mars' poles.



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Odyssey has also studied radiation levels at Mars in order to determine the potential risks for future human explorers.

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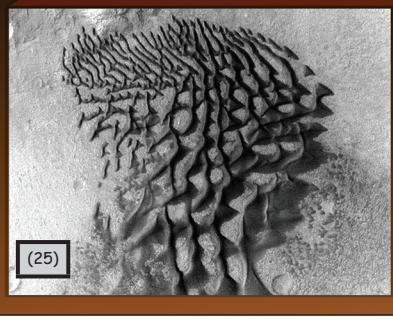

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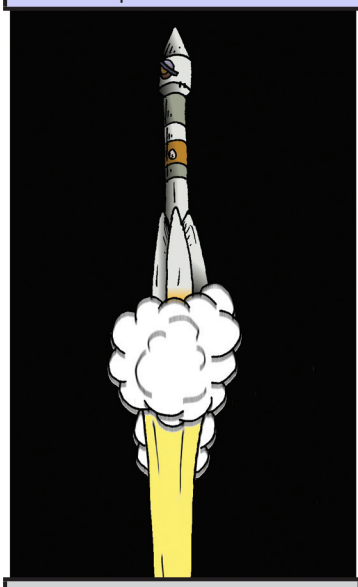
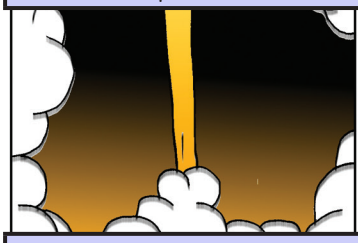
Today, Odyssey is still mapping martian minerals and is now part of a communications relay that allows scientists to 'talk' with other Mars missions. Odyssey is sure to play an important role in the future exploration of Mars.

On June 2, 2003, the European Space Agency (ESA) launched the Mars Express mission, adding to the international community of robotic explorers at Mars.

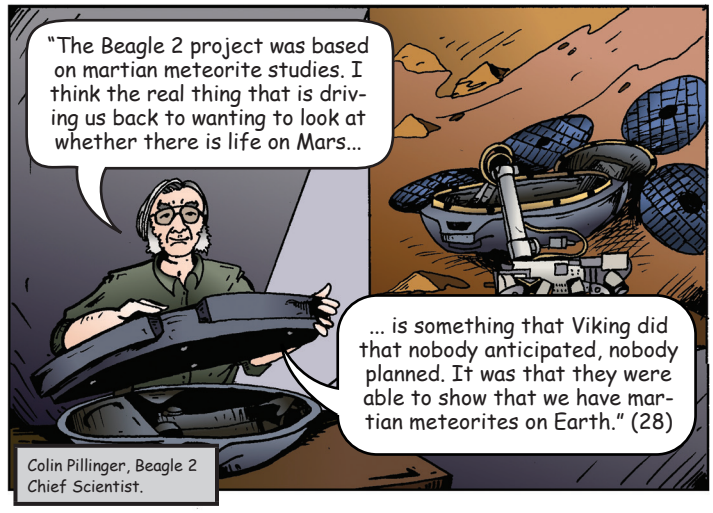


Rudi Schmidt, Mars Express Project Manager: "Mars Express is the first fully European mission to any planet. It is an exciting challenge for European technology." (27)

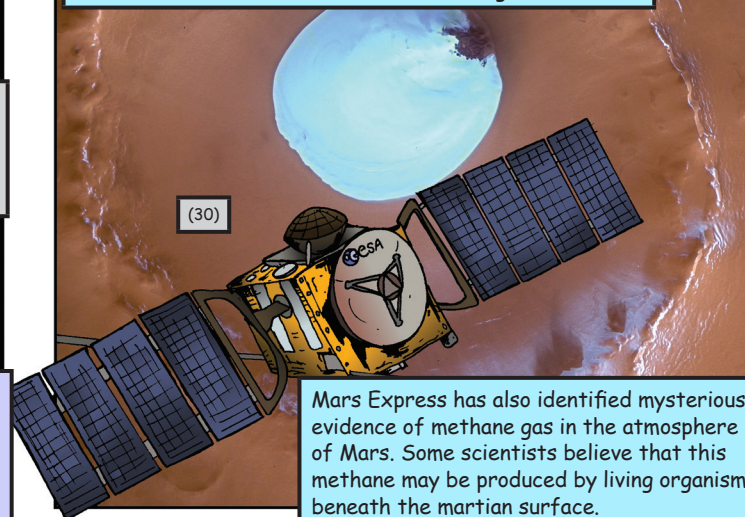
Mars Express was designed to re-launch some instruments that were lost on the Russian Mars 96 mission (28). One of its primary goals was to determine what happened to the water that once flowed on the planet's surface.



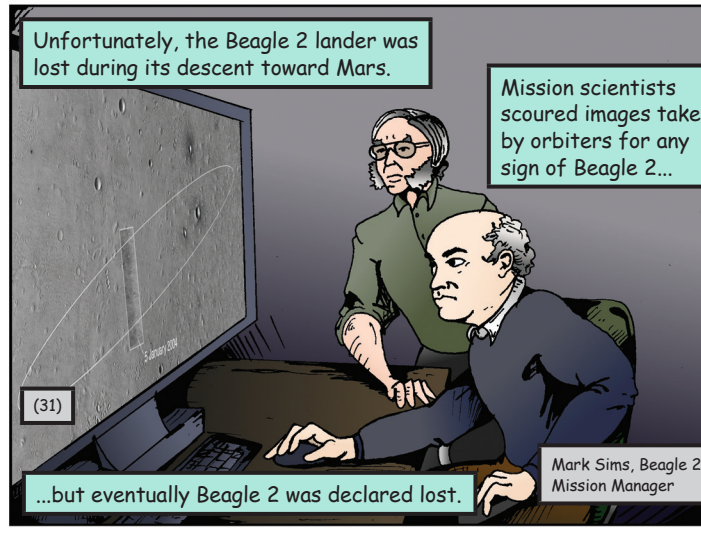
The mission also carried the Beagle 2 lander, which was the first mission since Viking designed specifically to look for evidence of past or present life.

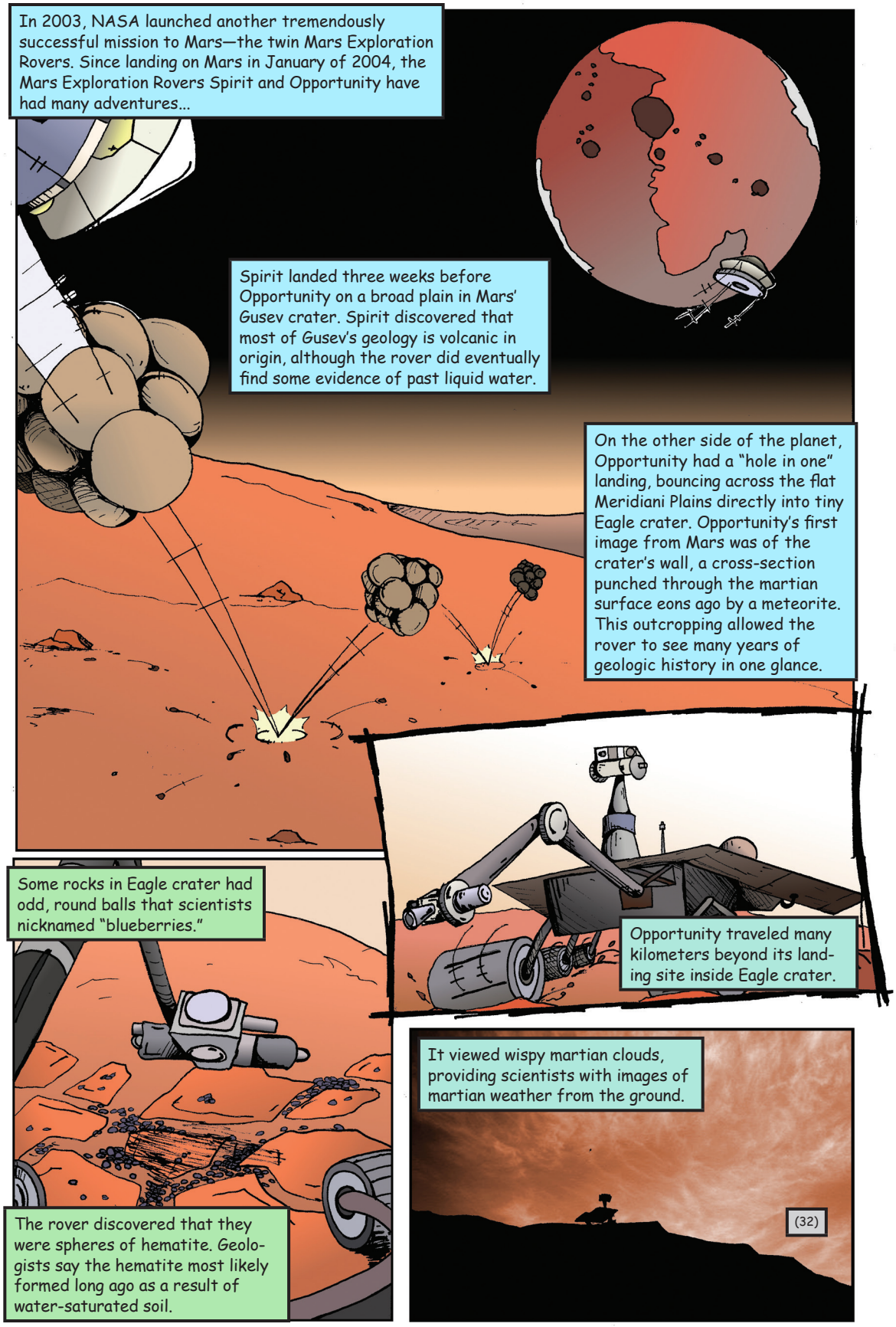


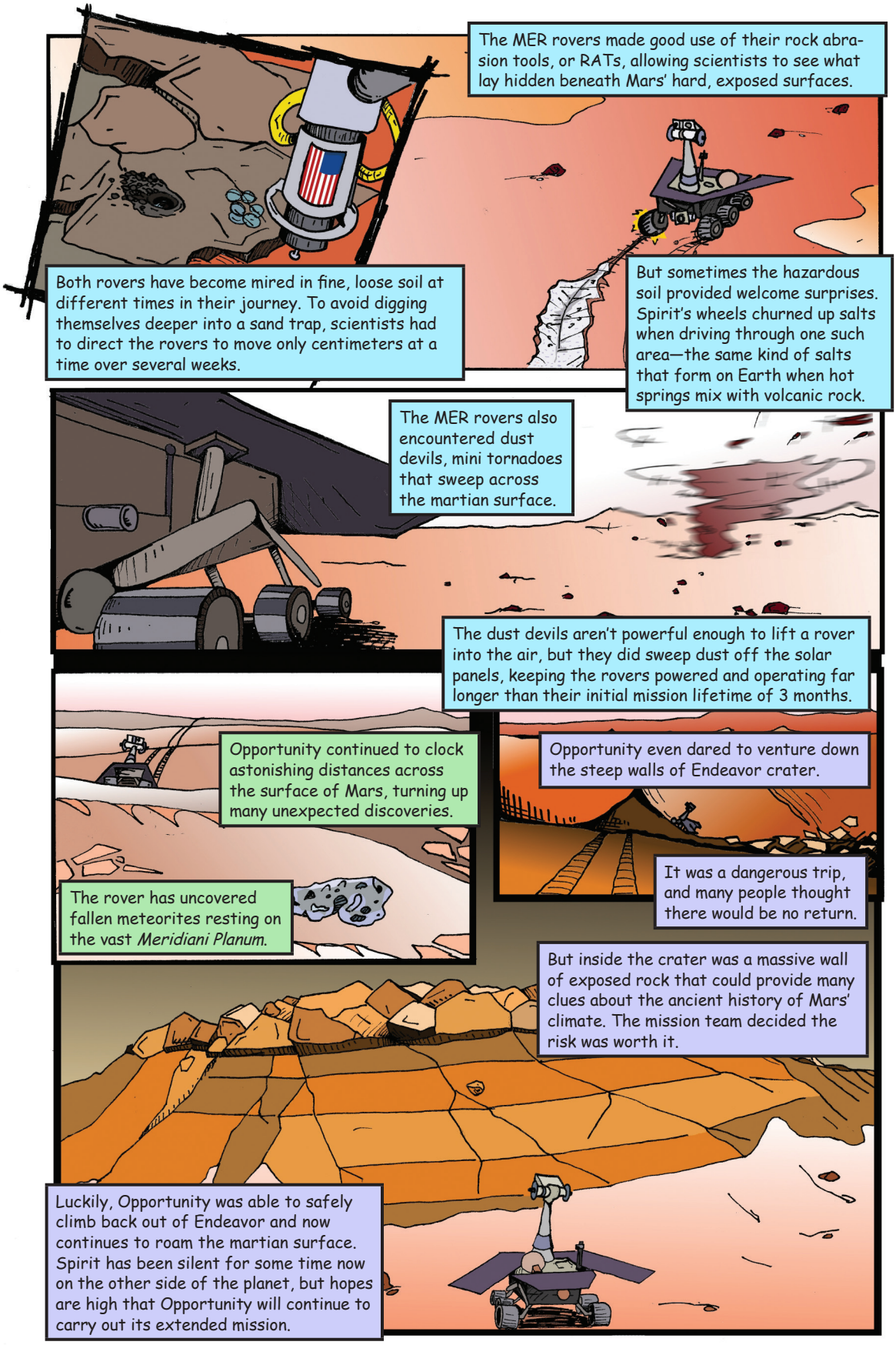
Mars Express was a huge success and continues to return valuable data (29). The orbiter has captured images of craters, volcanoes and other features in high resolution.



Mars Express has also identified mysterious evidence of methane gas in the atmosphere of Mars. Some scientists believe that this methane may be produced by living organisms beneath the martian surface.




In 2003, NASA launched another tremendously successful mission to Mars—the twin Mars Exploration Rovers. Since landing on Mars in January of 2004, the Mars Exploration Rovers Spirit and Opportunity have had many adventures...
Spirit landed three weeks before Opportunity on a broad plain in Mars' Gusev crater. Spirit discovered that most of Gusev's geology is volcanic in origin, although the rover did eventually find some evidence of past liquid water.
On the other side of the planet, Opportunity had a "hole in one" landing, bouncing across the flat Meridiani Plains directly into tiny Eagle crater. Opportunity's first image from Mars was of the crater's wall, a cross-section punched through the martian surface eons ago by a meteorite. This outcropping allowed the rover to see many years of geologic history in one glance.
Opportunity traveled many kilometers beyond its landing site inside Eagle crater.
Some rocks in Eagle crater had odd, round balls that scientists nicknamed "blueberries."
The rover discovered that they were spheres of hematite. Geologists say the hematite most likely formed long ago as a result of water-saturated soil.
It viewed wispy martian clouds, providing scientists with images of martian weather from the ground.


The MER rovers made good use of their rock abrasion tools, or RATs, allowing scientists to see what lay hidden beneath Mars' hard, exposed surfaces.
Both rovers have become mired in fine, loose soil at different times in their journey. To avoid digging themselves deeper into a sand trap, scientists had to direct the rovers to move only centimeters at a time over several weeks.
But sometimes the hazardous soil provided welcome surprises. Spirit's wheels churned up salts when driving through one such area—the same kind of salts that form on Earth when hot springs mix with volcanic rock.
The MER rovers also encountered dust devils, mini tornadoes that sweep across the martian surface.
The dust devils aren't powerful enough to lift a rover into the air, but they did sweep dust off the solar panels, keeping the rovers powered and operating far longer than their initial mission lifetime of 3 months.
Opportunity continued to clock astonishing distances across the surface of Mars, turning up many unexpected discoveries.
The rover has uncovered fallen meteorites resting on the vast *Meridiani Planum*.
Opportunity even dared to venture down the steep walls of Endeavor crater.
It was a dangerous trip, and many people thought there would be no return.
But inside the crater was a massive wall of exposed rock that could provide many clues about the ancient history of Mars' climate. The mission team decided the risk was worth it.
Luckily, Opportunity was able to safely climb back out of Endeavor and now continues to roam the martian surface. Spirit has been silent for some time now on the other side of the planet, but hopes are high that Opportunity will continue to carry out its extended mission.

On August 12, 2005, NASA added to the network of orbiters at Mars with the launch of the Mars Reconnaissance Orbiter (MRO). MRO is loaded with powerful instruments, including a shallow radar that can 'look' under the surface of Mars.

MRO's goals include determining whether or not liquid water was present on the surface of Mars for *long periods* of time (33). Other missions have collected evidence of flowing water, but was the liquid around long enough for life to evolve?

MRO has provided overhead views of the Mars terrain, helping scientists on Earth choose routes for the MER rovers to drive. These views are also used to select potential landing sites for future missions. Never before had so many robotic missions been in operation at Mars, both in orbit and on the surface. This network of missions is bringing astrobiologists closer and closer to unlocking Mars' mysteries.

In November of 2006, NASA received the final signal from the Mars Global Surveyor—after the spacecraft's *decade* of hard work (Page 12).

Glenn Cunningham, MGS manager through development and launch.

"When we watched the launch 10 years ago, we wondered if we would make the specified mission length. We certainly were not thinking of a 10-year operating life." (34)

(35)

Tom Thorpe, project manager for Mars Global Surveyor at JPL.

"It is an extraordinary machine that has done things the designers never envisioned despite a broken wing, a failed gyro and a worn-out reaction wheel. The builders and operating staff can be proud of their legacy of scientific discoveries and key support for subsequent missions." (34)

(36)

Olympus Mons

Ascraeus Mons

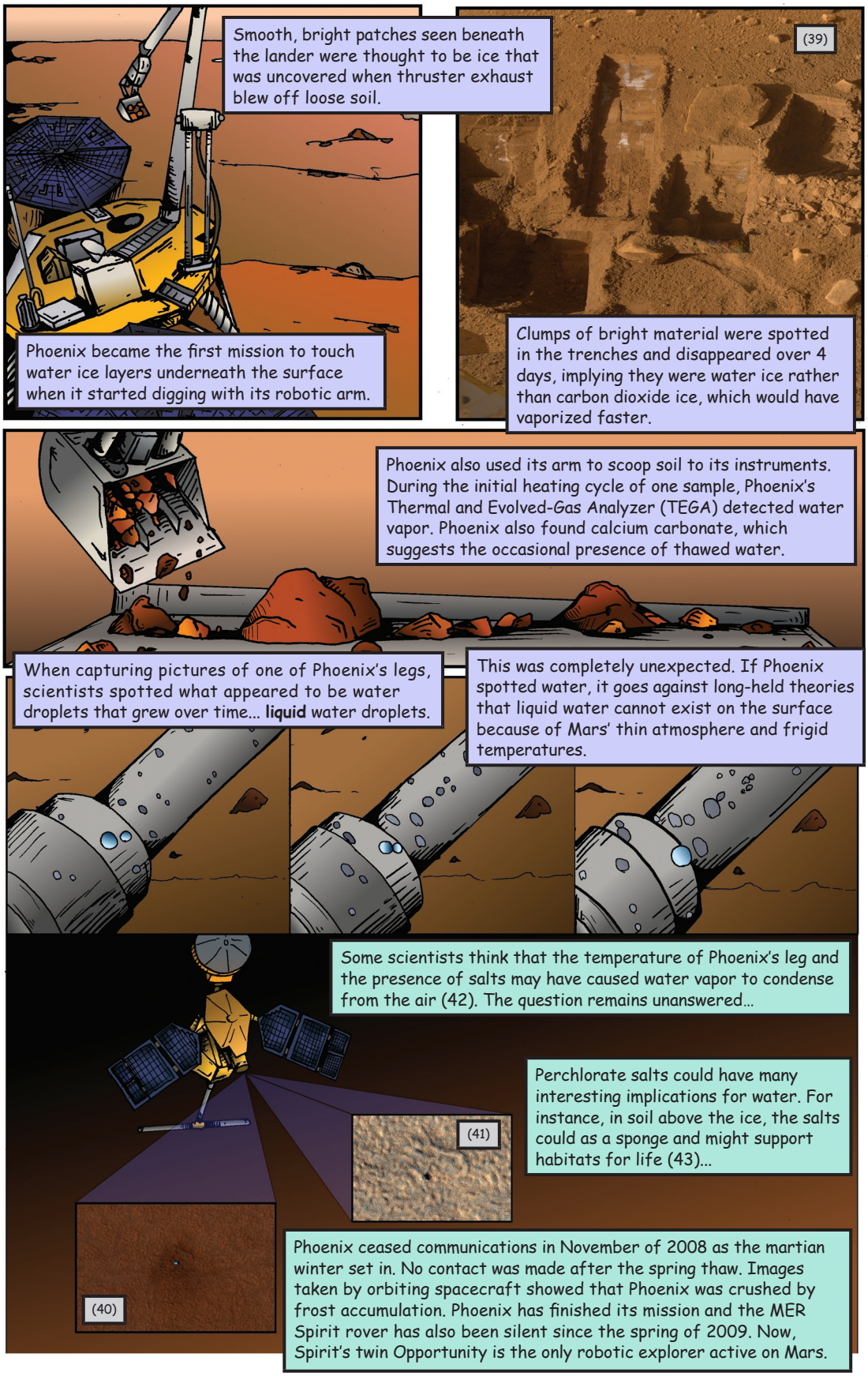
Pavonis Mons

After the final bow of MGS, NASA began preparing for another trip to the martian surface. The next mission would be based around the failed Mars Polar Lander (see page 13).

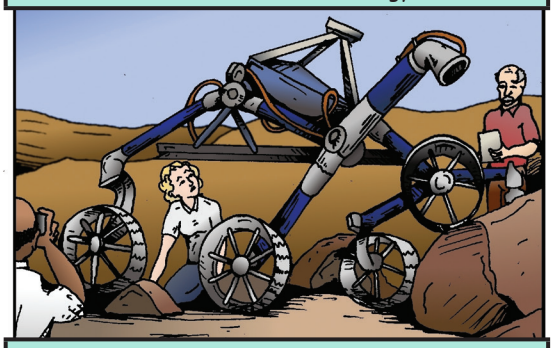
On August 4, 2007, the Phoenix Mars Lander launched toward the red planet. ESA's Mars Express later helped track the mission as it made the dangerous journey down to the surface of Mars.

With a successful touchdown on May 25, 2008, Phoenix became the first lander to explore Mars' northern polar region. Instruments on the lander were designed to search for evidence of past or present water, as well as other chemical elements that may be necessary for life. The mission would collect data to help answer important questions like, "Can the martian arctic support life?" and "What is the history of water at the Phoenix landing site?" (37)

(38)

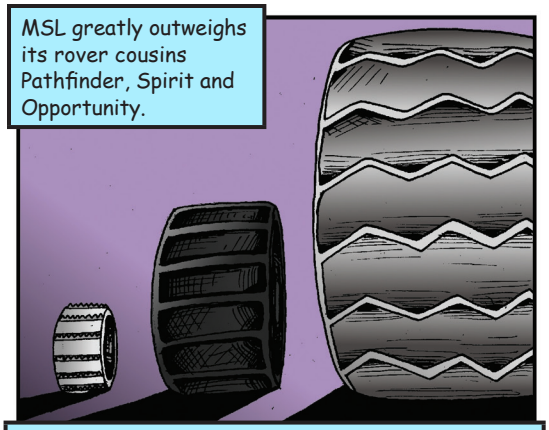

Smooth, bright patches seen beneath the lander were thought to be ice that was uncovered when thruster exhaust blew off loose soil.
Phoenix became the first mission to touch water ice layers underneath the surface when it started digging with its robotic arm.
(39)
Clumps of bright material were spotted in the trenches and disappeared over 4 days, implying they were water ice rather than carbon dioxide ice, which would have vaporized faster.
Phoenix also used its arm to scoop soil to its instruments. During the initial heating cycle of one sample, Phoenix's Thermal and Evolved-Gas Analyzer (TEGA) detected water vapor. Phoenix also found calcium carbonate, which suggests the occasional presence of thawed water.
When capturing pictures of one of Phoenix's legs, scientists spotted what appeared to be water droplets that grew over time... **liquid** water droplets.
This was completely unexpected. If Phoenix spotted water, it goes against long-held theories that liquid water cannot exist on the surface because of Mars' thin atmosphere and frigid temperatures.
Some scientists think that the temperature of Phoenix's leg and the presence of salts may have caused water vapor to condense from the air (42). The question remains unanswered...
(41)
Perchlorate salts could have many interesting implications for water. For instance, in soil above the ice, the salts could as a sponge and might support habitats for life (43)...
(40)
Phoenix ceased communications in November of 2008 as the martian winter set in. No contact was made after the spring thaw. Images taken by orbiting spacecraft showed that Phoenix was crushed by frost accumulation. Phoenix has finished its mission and the MER Spirit rover has also been silent since the spring of 2009. Now, Spirit's twin Opportunity is the only robotic explorer active on Mars.

Opportunity won't be alone for long. In 2011, NASA will return to the surface of Mars with a large-scale mission dedicated to Astrobiology.



The Mars Science Laboratory (MSL) is the first roving analytical laboratory to be sent to Mars.

MSL greatly outweighs its rover cousins Pathfinder, Spirit and Opportunity.



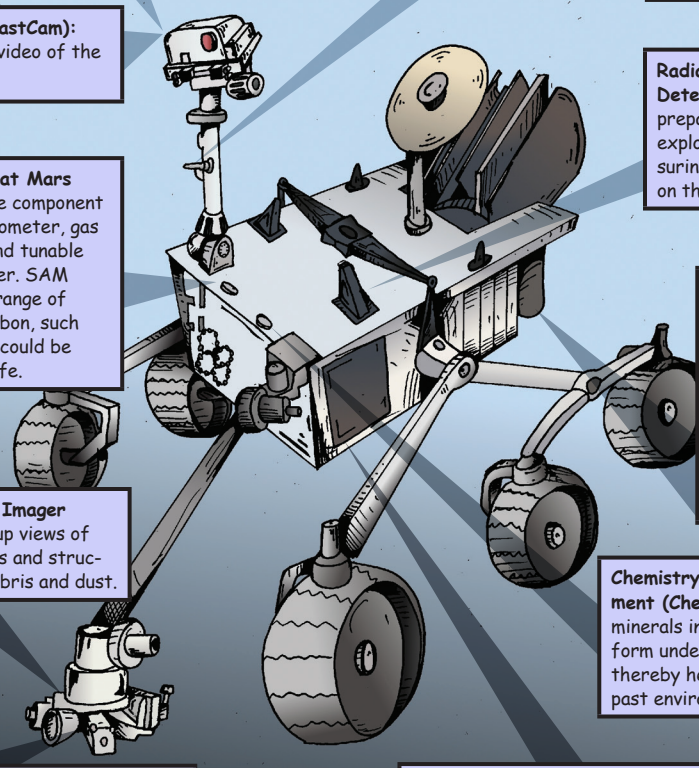
Its suite of instruments is the biggest and most advanced scientific package ever sent to the martian surface.

Chemistry & Camera (ChemCam): fires a laser to vaporize materials from small areas less than 1 millimeter. ChemCam can vaporize the dust from the surface and analyze the underlying rock. ChemCam can even analyze rocks from a distance.

Rover Environmental Monitoring Station (REMS): This weather monitoring station from the Centro de Astrobiologia (CAB) is contributed to MSL by the Spanish government.

MSL Entry, Descent, and Landing Instrument (MEDLI): This instrument suite will collect engineering data during MSL's high-speed entry into the martian atmosphere, providing invaluable data for engineers designing future Mars missions. MEDLI is mounted inside the heatshield that will protect MSL during atmospheric entry.

Mast Camera (MastCam): color images and video of the martian surface.



Radiation Assessment Detector (RAD): Will help prepare for future human exploration of Mars by measuring high-energy radiation on the martian surface.

Sample Analysis at Mars (SAM): A massive component that has a spectrometer, gas chromatograph and tunable laser spectrometer. SAM will search for a range of compounds of carbon, such as methane, that could be associated with life.

Dynamic Albedo of Neutrons (DAN): Funded by the Russian Federal Space Agency, this pulsing neutron generator will detect water content in ice and minerals, and search for layers of water and ice up to 2 meters below the surface.

Mars Hand Lens Imager (MAHLI): close-up views of minerals, textures and structures in rocks, debris and dust.

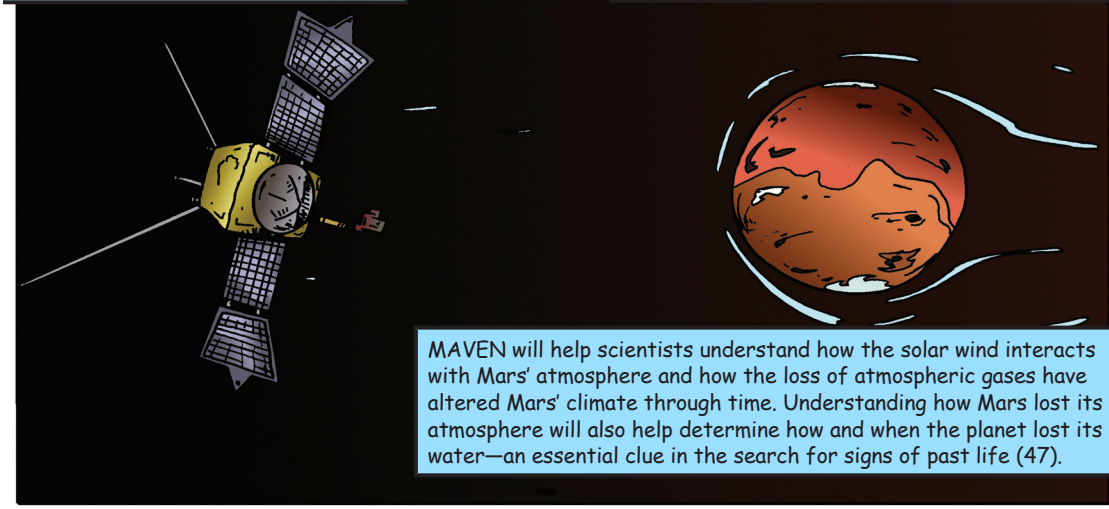
Chemistry and Mineralogy instrument (ChemMin): Will determine the minerals in rocks and soil. Minerals form under certain conditions and can thereby help scientists determine past environments on Mars.

Alpha Particle X-Ray Spectrometer (APXS): measure the chemical elements in rocks and soils [funded by the Canadian Space Agency].

Mars Descent Imager (MARDI): color video during MSL's descent to the martian surface, providing an 'astronaut's' view of the terrain for scientists deciding where the rover will drive and explore.

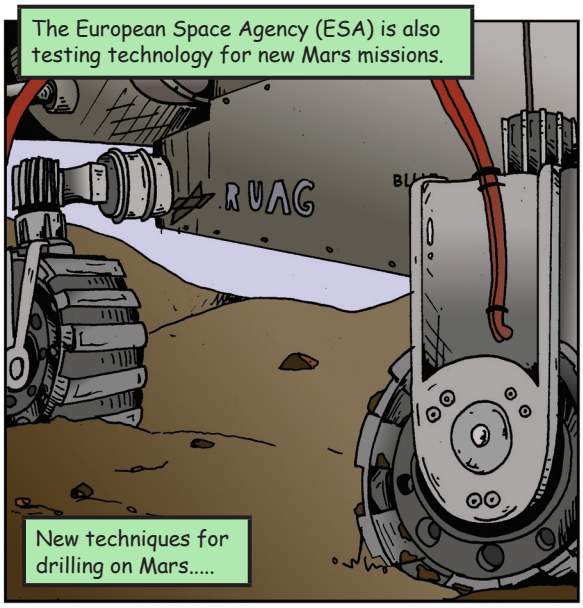
After MSL, NASA's next mission to Mars will be the MAVEN orbiter, currently scheduled to launch in 2013.

The Mars Atmosphere and Volatile EvolutioN (MAVEN) mission will be the first orbiter dedicated to studying the planet's upper atmosphere.



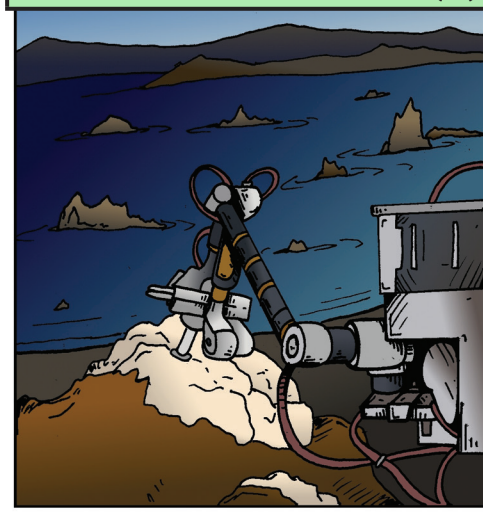
MAVEN will help scientists understand how the solar wind interacts with Mars' atmosphere and how the loss of atmospheric gases have altered Mars' climate through time. Understanding how Mars lost its atmosphere will also help determine how and when the planet lost its water—an essential clue in the search for signs of past life (47).

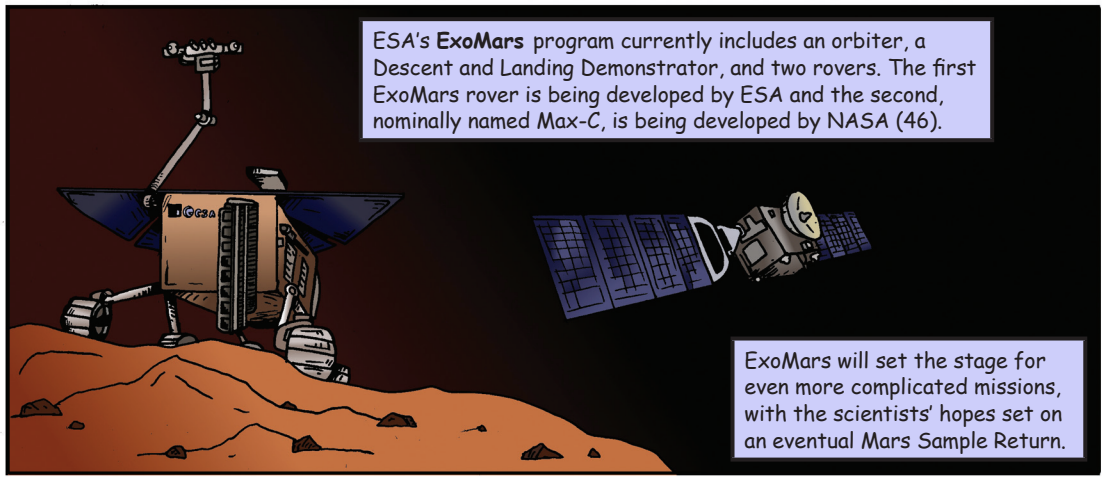
The European Space Agency (ESA) is also testing technology for new Mars missions.



New techniques for drilling on Mars.....

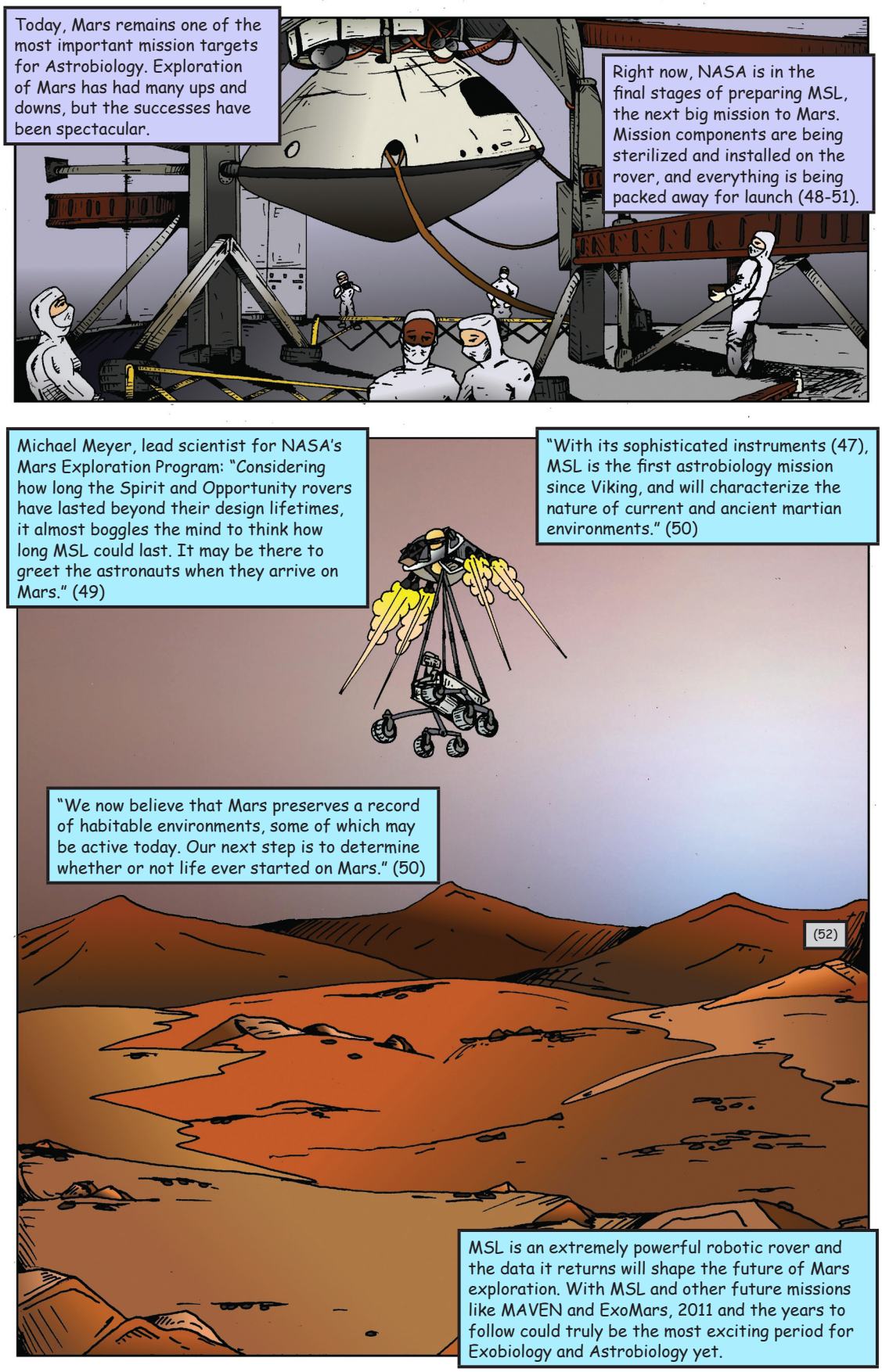
...and tools for collecting samples are being prepared in Earth test-beds, including arctic islands and California's remote Mono Lake (45).





ESA's **ExoMars** program currently includes an orbiter, a Descent and Landing Demonstrator, and two rovers. The first ExoMars rover is being developed by ESA and the second, nominally named Max-C, is being developed by NASA (46).

ExoMars will set the stage for even more complicated missions, with the scientists' hopes set on an eventual Mars Sample Return.


Today, Mars remains one of the most important mission targets for Astrobiology. Exploration of Mars has had many ups and downs, but the successes have been spectacular.
Right now, NASA is in the final stages of preparing MSL, the next big mission to Mars. Mission components are being sterilized and installed on the rover, and everything is being packed away for launch (48-51).
Michael Meyer, lead scientist for NASA's Mars Exploration Program: "Considering how long the Spirit and Opportunity rovers have lasted beyond their design lifetimes, it almost boggles the mind to think how long MSL could last. It may be there to greet the astronauts when they arrive on Mars." (49)
"With its sophisticated instruments (47), MSL is the first astrobiology mission since Viking, and will characterize the nature of current and ancient martian environments." (50)
"We now believe that Mars preserves a record of habitable environments, some of which may be active today. Our next step is to determine whether or not life ever started on Mars." (50)
(52)
MSL is an extremely powerful robotic rover and the data it returns will shape the future of Mars exploration. With MSL and other future missions like MAVEN and ExoMars, 2011 and the years to follow could truly be the most exciting period for Exobiology and Astrobiology yet.

Astrobiology

A History of Exobiology and Astrobiology at NASA

Further Resources and References cited in this issue:

1. The background in this page is an image of M72: A Globular Cluster of Stars captured by the Hubble Space Telescope. M72 lies about 50,000 light years away and can be seen with a small telescope pointed in the direction of the constellation Water Bearer (Aquarius). This image shows about 100,000 of M72's stars and spans about 50 light years. Credit: NASA, ESA
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6. Mariner 4 image, the first close-up image ever taken of Mars. The image is centered at 37 N, 187 W and is roughly 330 km by 1200 km. The resolution is roughly 5 km and north is up. Available from the NASA image archive at: http://nssdc.gsfc.nasa.gov/imgcat/html/object_page/m04_01d.html
7. Mariner 4 image, the first image to clearly show unambiguous craters on the surface of Mars. The area is roughly 262 km by 310 km and shows the region south of Amzazonis Planitia at 14 S, 174 W. North is at roughly 11:00 in this image. Credit: NASA
8. This image of Venus was actually acquired by Mariner 10 during its flyby of the planet. Mariner 5 was built as a backup to the successful Mariner 4 mission, and when its TV camera was removed when the craft was adapted for travel to Venus. Instead of photographing Venus, Mariner 5 probed the planet's atmosphere with its suite of instruments. Credit: NASA/JPL
9. The cratered surface of Mars taken by Mariner 6. Image Credit: NASA/JPL
10. Mariner 7, following Mariner 6's flyby on July 31, has its closest approach at a distance of 3,524 kilometers (2,190 miles). Image Credit: NASA/JPL
11. Mariner 9 view of the "labyrinth" at the western end of Vallis Marineris on Mars. Linear graben, grooves, and crater chains dominate this region, along with a number of flat-topped mesas. The image is roughly 400 km across, centered at 6 S, 105 W, at the edge of the Tharsis bulge. North is up. (Mariner 9, MTVS 4187-45). Credit: NASA/JPL
12. Mariner 9 image of the north polar cap of Mars. The image was taken on 12 October 1972, about one-half Martian month after summer solstice, at which time the cap had reached its minimal extent. The cap is about 1000 km across. The interior dark markings are frost-free sun-facing slopes. A smooth layered sedimentary deposit underlies the cap. The image is centered at 89 N, 200 W. (Mariner 9, MTVS 4297-47). Credit: NASA/JPL
13. Mariner 10 oblique view of Wren crater and surroundings on Mercury. Wren crater is barely visible at the lower center of the image, containing a number

of craters within its 215 km diameter floor. Running along the right side of the image is Antoniadi Dorsum. North is at 1:00. (Mariner 10, Atlas of Mercury, Fig. 2-10) (edge of planet). Credit: NASA

14. Mariner 10 image of Brahms Crater, Mercury. This image of the 75 km diameter crater was taken on the first flyby. Note the central peak. North is up. (Mariner 10, Atlas of Mercury, Fig. 3-2). Credit: NASA
15. Other missions in the Soviet Mars series were unsuccessful, including the lander attempt of Mars 7.
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18. The first image transmitted by the Viking 1 Lander from the surface of Mars on July 20, 1976. Credit: NASA Viking Image Archive
19. Viking 1 Camera 1 Mosaic of Chryse Planitia. Credit: NASA Viking Image Archive
20. Astrobiology Magazine (www.astrobio.net), "Five Year Retrospective: Mars Pathfinder, Interview with Pathfinder Project Scientist, Matt Golombek". Available at: http://www.astrobio.net/interview/282/five-year-retrospective-mars-pathfinder
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23. Light Deposits Indicate Water Flowing on Mars. This figure shows MGS images of the southeast wall of the unnamed crater in the Centauri Montes region, as it appeared in August 1999, and later in September 2005. No light-toned deposit was present in August 1999, but appeared by February 2004. Credit: NASA/JPL/Malin Space Science Systems
24. A false-color mosaic focuses on one junction in *Noctis Labyrinthus* where canyons meet to form a depression 4,000 meters (13,000 feet) deep. Dust (blue tints) lies on the upper surfaces, while rockier material (warmer colors) lies below. The pictures used to create this mosaic image were taken from April 2003 to September 2005 by the Thermal Emission Imaging System instrument on NASA's Mars Odyssey orbiter. Image credit: NASA/JPL-Caltech/ASU
25. Fans and ribbons of dark sand dunes creep across the floor of Bunge Crater in response to winds blowing from the direction at the top of the picture. This image was taken in January 2006 by the Thermal Emission Imaging System (THEMIS) instrument on NASA's Mars Odyssey orbiter. The pictured location on Mars is 33.8 degrees south latitude, 311.4 degrees east longitude. Image Credit: NASA/JPL-Caltech/ASU
26. This two frame mosaic shows part of Aureum Chaos. This color treatment is the result of a collaboration between THEMIS team members at Cornell University and space artist Don Davis, who is an expert on true-color renderings of planetary and astronomical objects. Image Credit: NASA/JPL/ASU
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30. Image taken by the Mars Express High Resolution Stereo Camera (HRSC) showing water ice on the floor of a crater near the Martian north pole. Credit: ESA/DLR/FU Berlin (G. Neukum)
31. Beagle 2 Landing site in *Isidis Planitia*. **MOC2-835a**: Beagle 2 December 25, 2003, landing ellipse. Credit: Mars Global Surveyor Mars Orbital Camera Image.
32. This photo, taken by NASA's Opportunity rover, shows Mars' thin, diffuse clouds. Image credit: NASA/JPL-Caltech
33. NASA. Mars Reconnaissance Orbiter Mission Pages: Science Goals. Available at: http://www.nasa.gov/mission_pages/MRO/mission/science-goals.html
34. Astrobiology Magazine. 2006. "Astrobiology Top 10: MGS Bows Out". Available at: http://www.astrobio.net/index.php?option=com_retrospection&task=detail&id=2191
35. Details in a fan-shaped deposit discovered by NASA's Mars Global Surveyor. Credit: NASA/JPL/Malin Space Science Systems
36. This is a shaded relief image derived from Mars Orbiter Laser Altimeter data, which flew onboard the Mars Global Surveyor. The image shows Olympus Mons and the three Tharsis Montes volcanoes: Arsia Mons, Pavonis Mons, and Ascraeus Mons from southwest to northeast. Credit: NASA
37. University of Arizona. Phoenix Mars Mission. Available at: http://phoenix.lpl.arizona.edu/mission.php
38. This image, one of the first captured by NASA's Phoenix Mars Lander, shows the vast plains of the northern polar region of Mars. The flat landscape is strewn with tiny pebbles and shows polygonal cracking, a pattern seen widely in Martian high latitudes and also observed in permafrost terrains on Earth. Credit: NASA/JPL-Caltech/University of Arizona
39. Images from the Surface Stereo Imager camera on NASA's Phoenix Mars Lander shows several trenches dug by Phoenix. Credit: NASA/JPL-Caltech/University of Arizona/Texas A&M University
40. This image taken by the HiRISE instrument onboard the Mars Reconnaissance Orbiter shows the Phoenix lander in 2008 after landing and deployment of the solar panels. Image Title: "Phoenix Lander Hardware: EDL +22 (PSP_008591_2485)". Credit: NASA/JPL/University of Arizona
41. This HiRISE image shows the Phoenix lander after one year on Mars. The image is a close match to the season and illumination and viewing angles of some of the first HiRISE images acquired after the successful landing on 25 May 2008. The shadow that is cast by the lander is different than the previous year, indicating that Phoenix has suffered structural damage. Image Title: "Phoenix Lander after One Mars Year (ESP_017716_2485)". Credit: NASA/JPL/University of Arizona
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51. Space.com. 2004. “Mars Science Laboratory: New Rover, New Science Equipment”. Available at: http://www.space.com/scienceastronomy/marssciencelab_science_040427.html
52. Background image: Image from NASA’s Mars Exploration Rover Spirit of the Sun sinking below the rim of Gusev crater on May 19, 2005. Credit: NASA/JPL/Texas A&M/Cornell

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