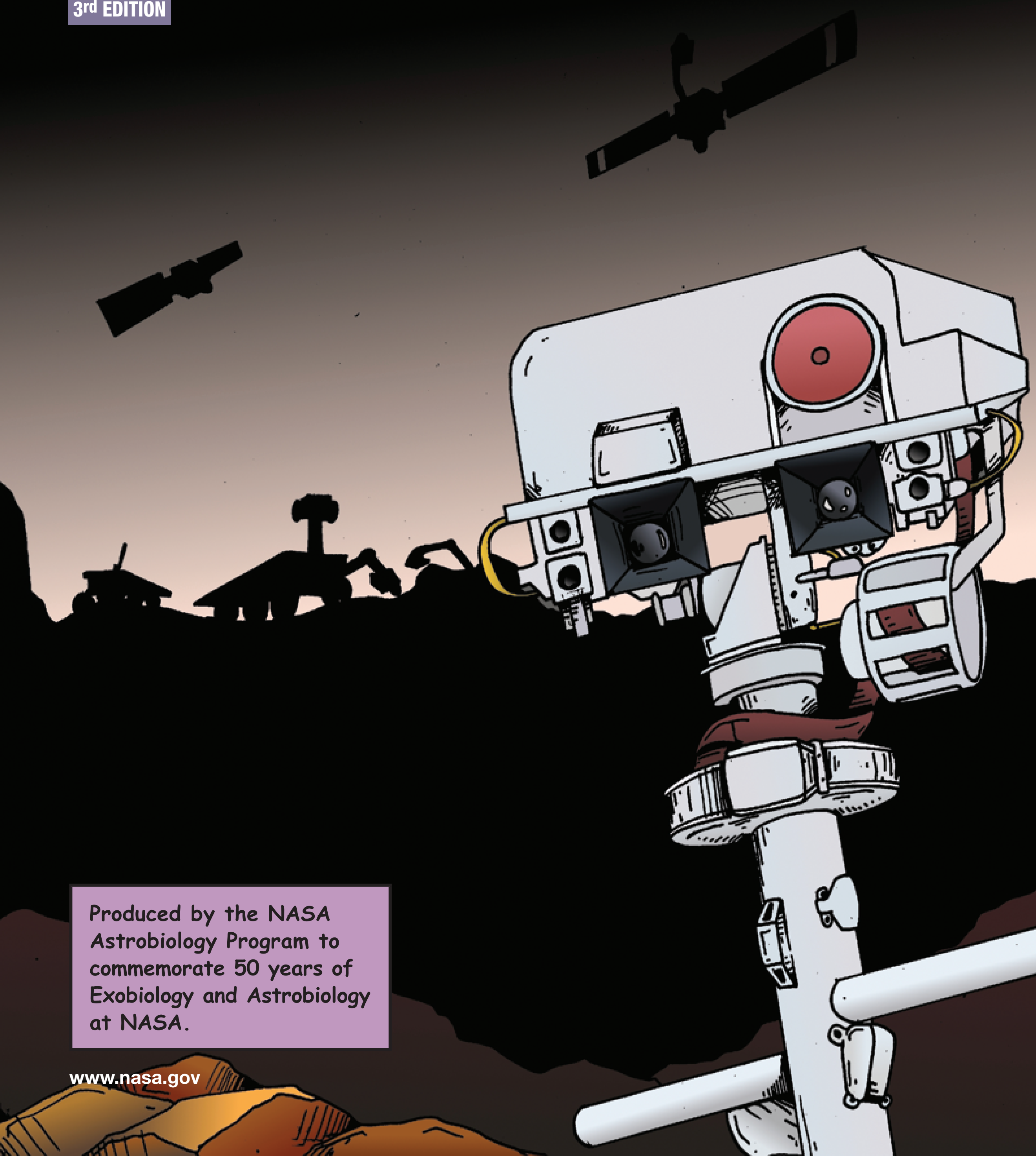
National Aeronautics and Space Administration

Issue #2

3rd EDITION

ASTROBIOLOGY

The Story of our Search for Life in the Universe



Produced 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.

Concept & Story

Mary Voytek
Linda Billings
Aaron L. Gronstal

Artwork

Aaron L. Gronstal

Script

Aaron L. Gronstal and Leslie Mullen

Editor

Linda Billings

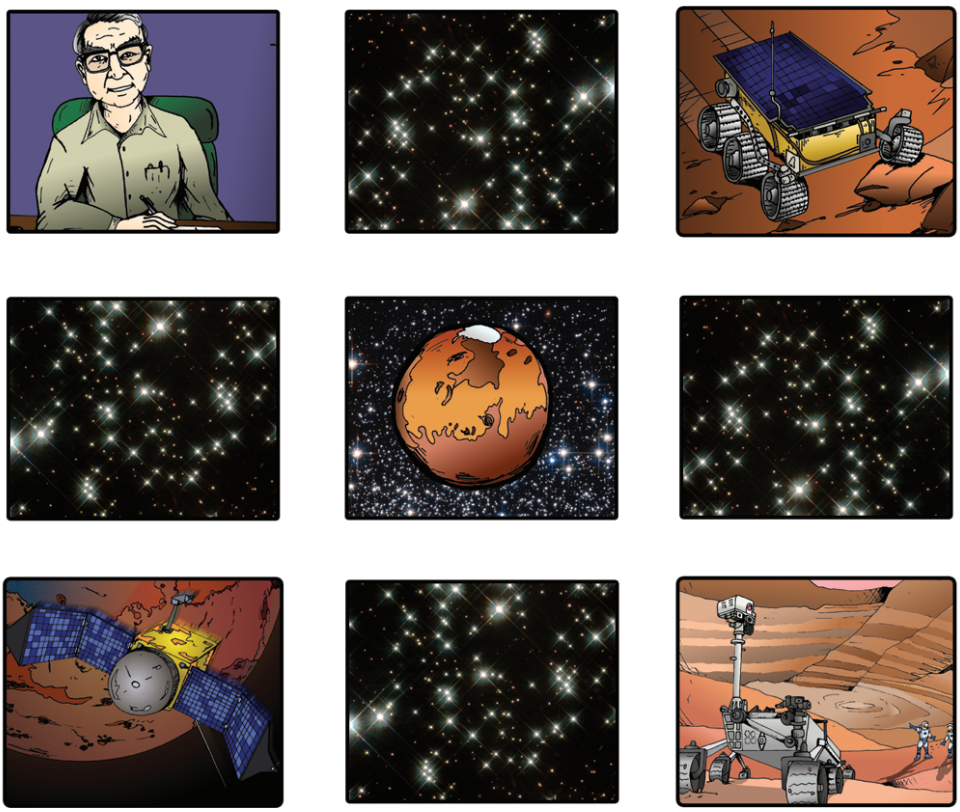
Layout

Jenny Mottar

Special thanks to Daniella Scalice and Michael Meyer

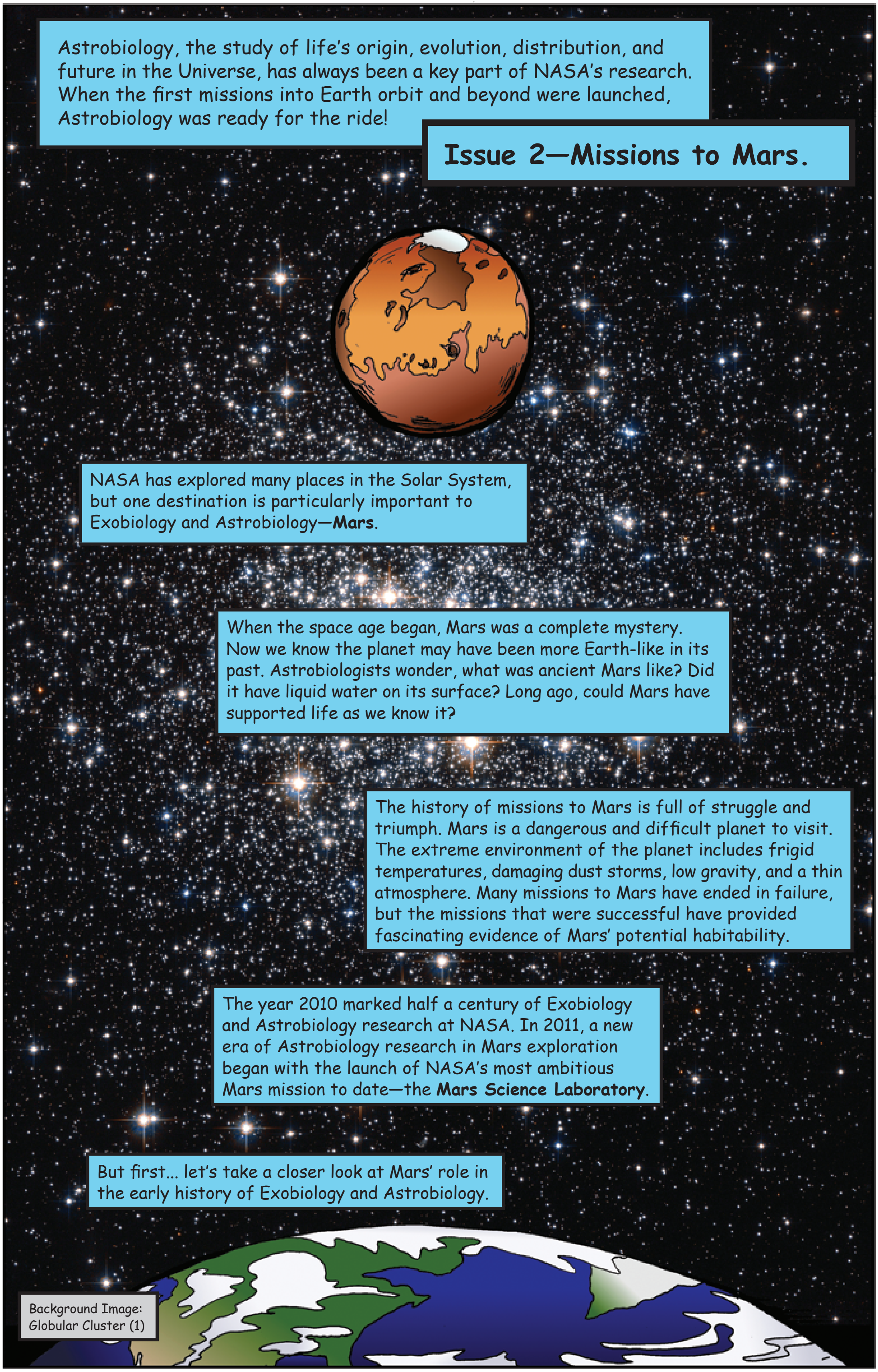
First edition printed in 2011

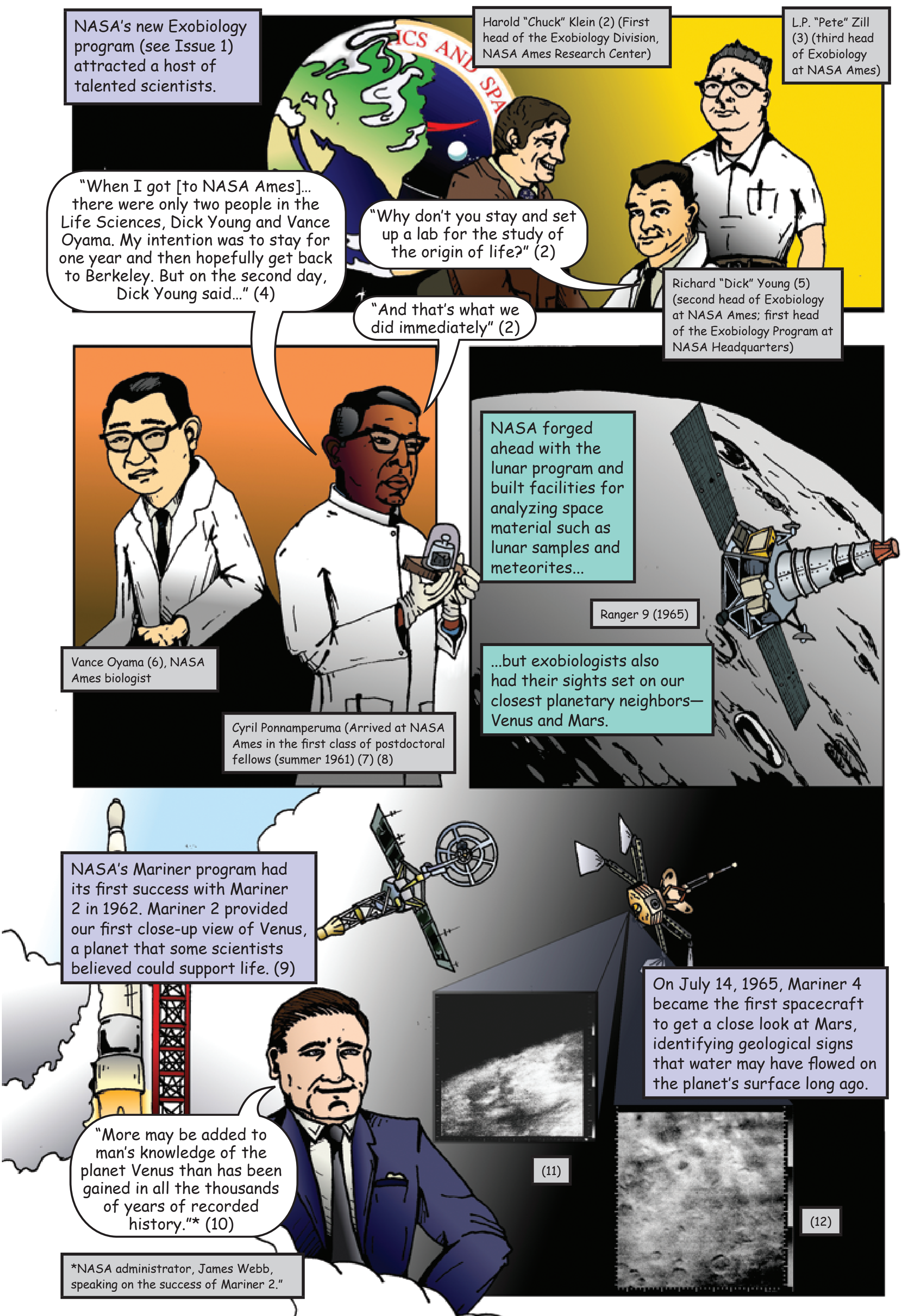
Issue #2—Missions to Mars

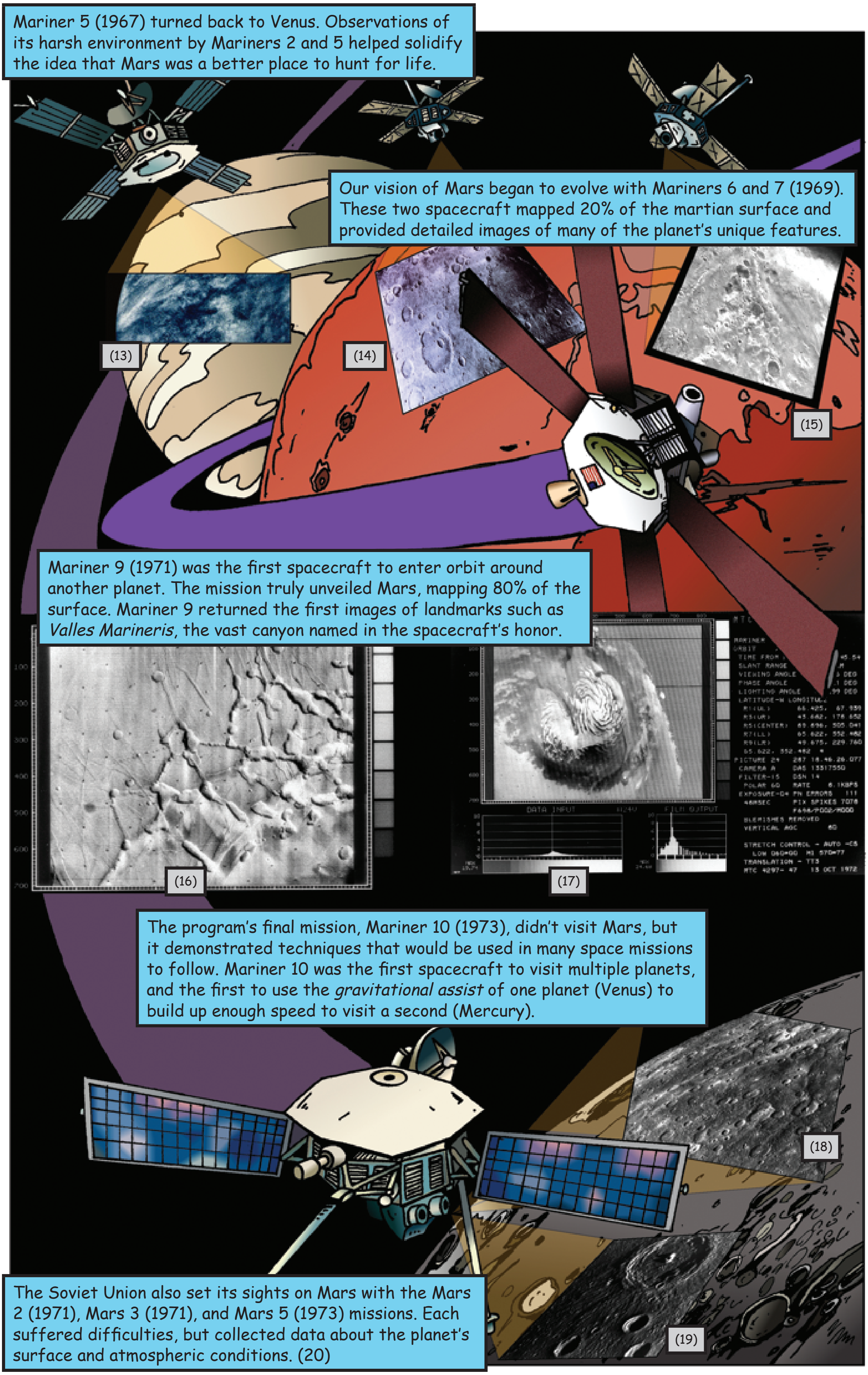


The year 2010 marked the 50th anniversary of NASA's Exobiology Program, established in 1960 and expanded into a broader Astrobiology Program in the 1990s. To commemorate the past half century of research, we are telling the story of how this field developed and how the search for life elsewhere became 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.

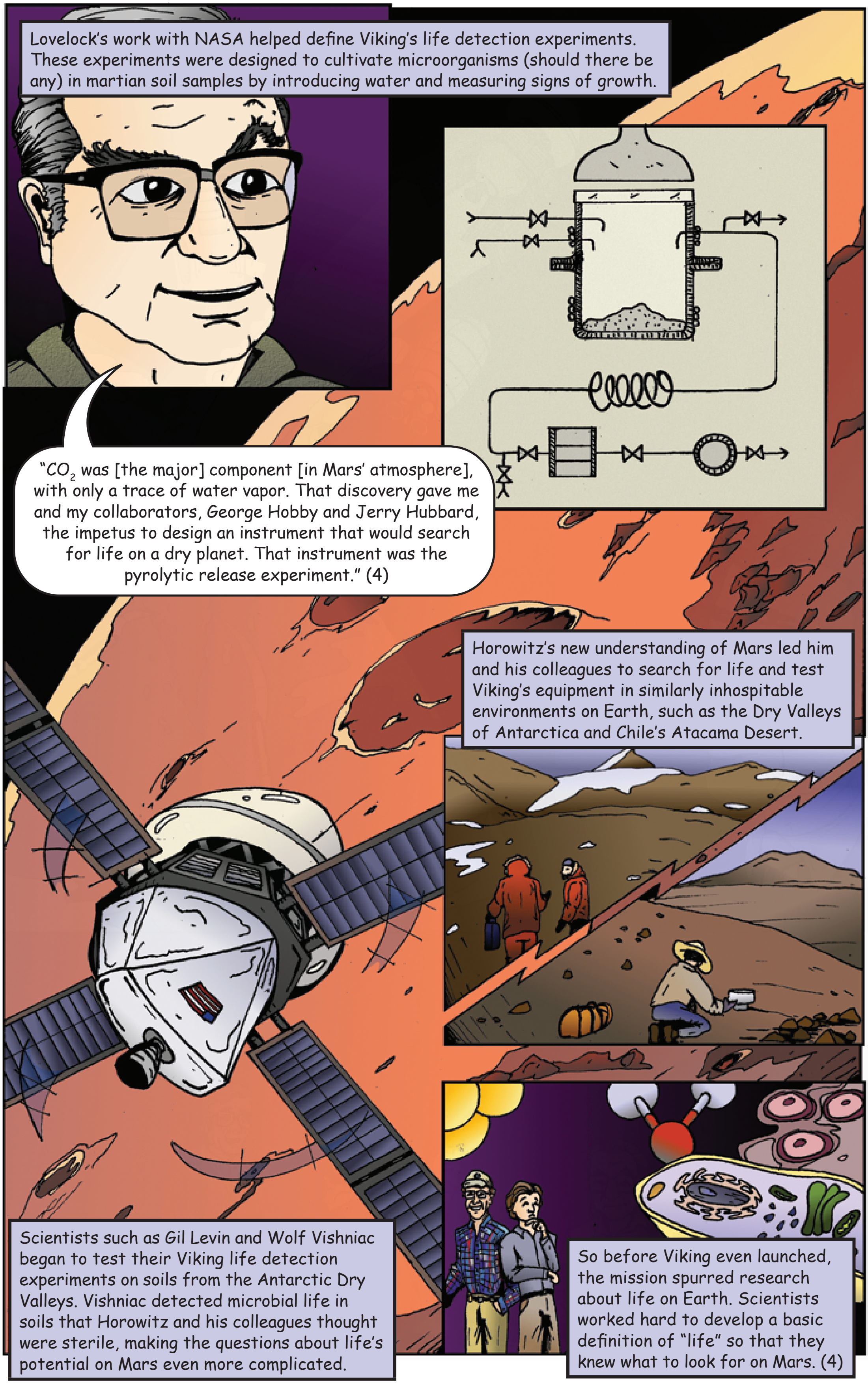
-Linda Billings, Editor

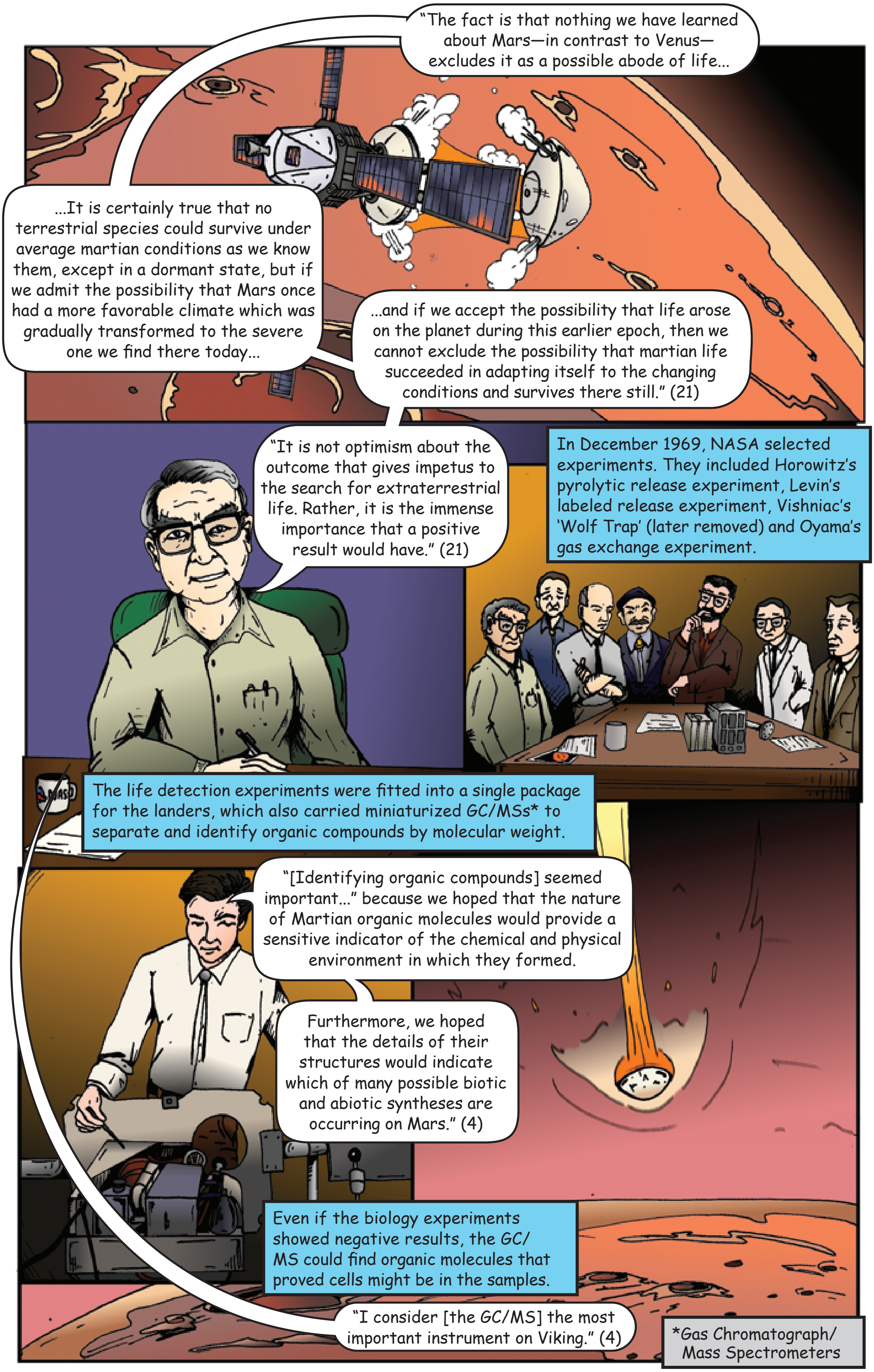

Astrobiology, the study of life's origin, evolution, distribution, and future in the Universe, has always been a key part of NASA's research. When the first missions into Earth orbit and beyond were launched, Astrobiology was ready for the ride!
Issue 2—Missions to Mars.
NASA has explored many places in the Solar System, but one destination is particularly important to Exobiology and Astrobiology—**Mars**.
When the space age began, Mars was a complete mystery. Now we know the planet may have been more Earth-like in its past. Astrobiologists wonder, what was ancient Mars like? Did it have liquid water on its surface? 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, a new era of Astrobiology research in Mars exploration began 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 early history of Exobiology and Astrobiology.
Background Image: Globular Cluster (1)

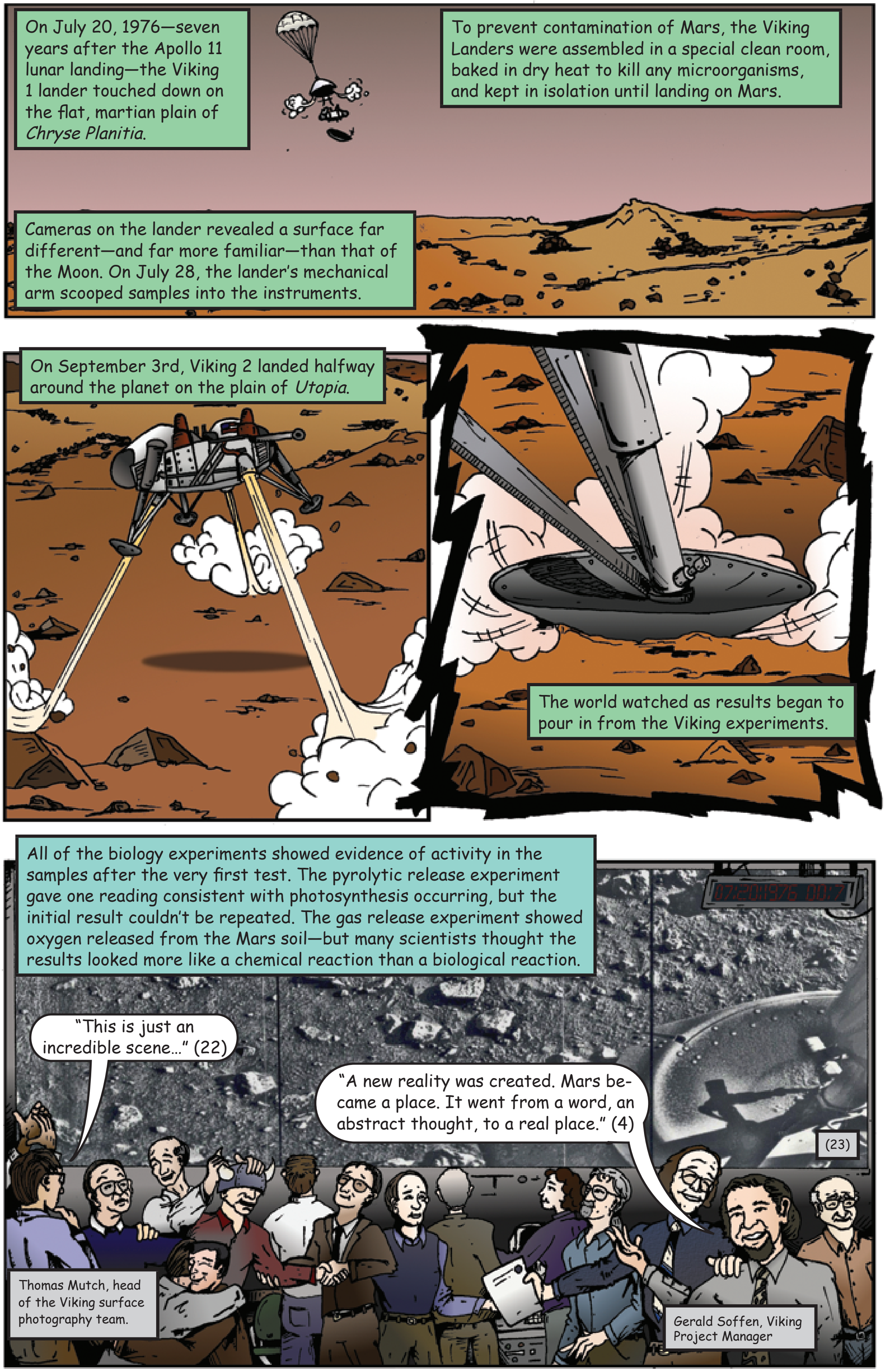

NASA's new Exobiology program (see Issue 1) attracted a host of talented scientists.
Harold "Chuck" Klein (2) (First head of the Exobiology Division, NASA Ames Research Center)
L.P. "Pete" Zill (3) (third head of Exobiology at NASA Ames)
"When I got [to NASA Ames]... there were only two people in the 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..." (4)
"Why don't you stay and set up a lab for the study of the origin of life?" (2)
Richard "Dick" Young (5) (second head of Exobiology at NASA Ames; first head of the Exobiology Program at NASA Headquarters)
"And that's what we did immediately" (2)
Vance Oyama (6), NASA Ames biologist
Cyril Ponnamperuma (Arrived at NASA Ames in the first class of postdoctoral fellows (summer 1961) (7) (8)
NASA forged ahead with 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. (9)
On July 14, 1965, Mariner 4 became the first spacecraft to get a close look at Mars, identifying geological signs that water may have flowed on the planet's surface long ago.
"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."* (10)
(11)
(12)
*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 and provided detailed images of many of the planet's unique features.
(13)
(14)
(15)
Mariner 9 (1971) was the first spacecraft to enter orbit around another planet. The mission truly unveiled Mars, mapping 80% of the surface. Mariner 9 returned the first images of landmarks such as *Valles Marineris*, the vast canyon named in the spacecraft's honor.
(16)
(17)
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).
(18)
(19)
The Soviet Union also set its sights on Mars with the Mars 2 (1971), Mars 3 (1971), and Mars 5 (1973) missions. Each suffered difficulties, but collected data about the planet's surface and atmospheric conditions. (20)

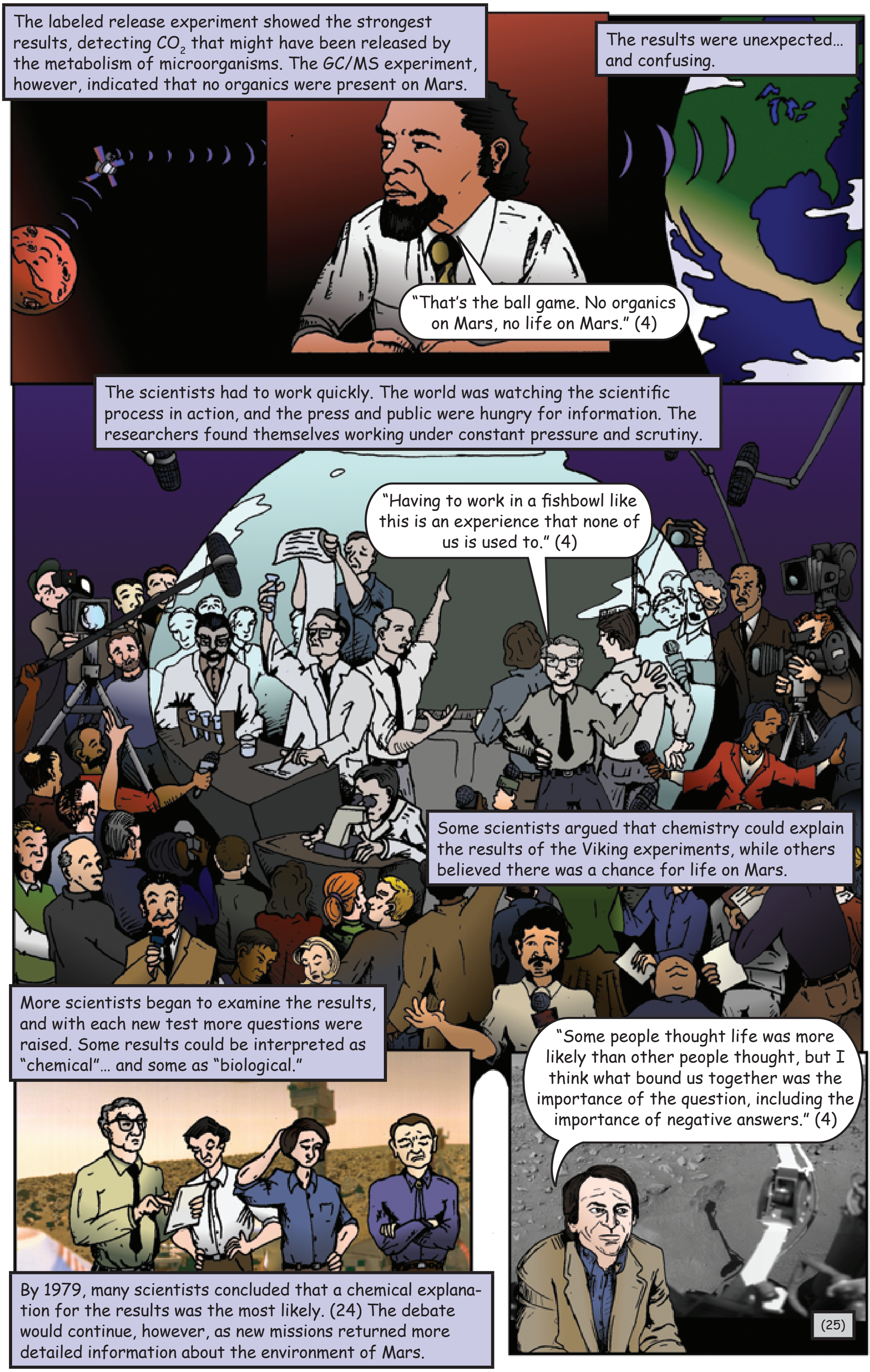

As early as 1959, NASA was developing instruments for detecting life. Mars quickly topped the list of places where NASA could put this technology to use.
This early focus on Mars led to a major milestone in the history of Exobiology and Astrobiology. In 1975, NASA launched an ambitious planetary exploration endeavor—the twin Viking missions.
The Viking 1 and Viking 2 missions each 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." (4)
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.
"We must concentrate on concepts that are not 'Earthcentric.' We ought to look for entropy-reduction phenomena." (8)
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.
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). (4)
I think I know some people you should meet...
But Lovelock's groundbreaking theories are a story for another time...

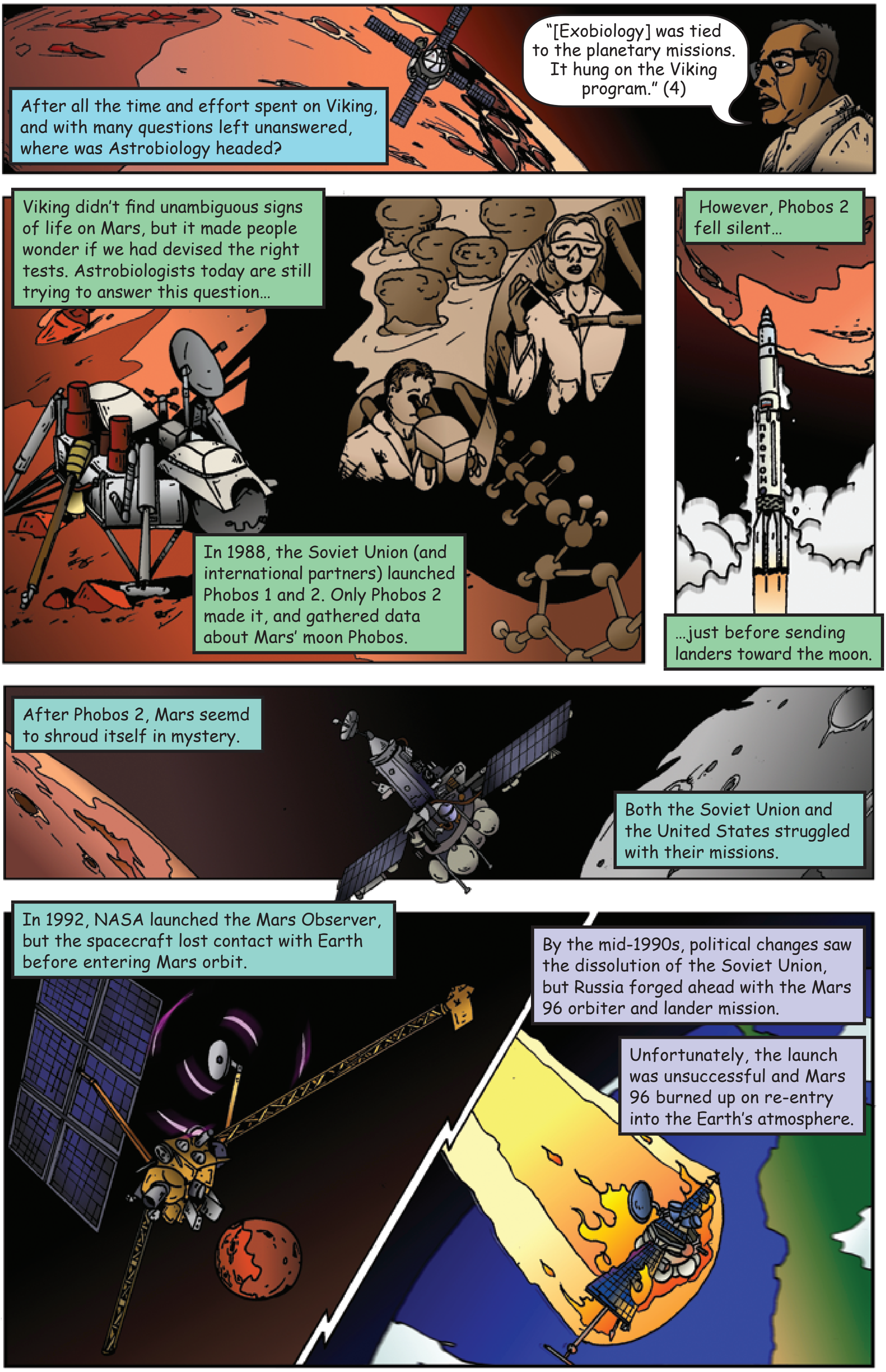

Lovelock's work with NASA helped define Viking's life detection experiments. These experiments were designed to cultivate microorganisms (should there be any) in martian soil samples by introducing water and measuring signs of growth.
"CO_2 was [the major] component [in Mars' atmosphere], with only a 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." (4)
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 spurred research about life on Earth. Scientists worked hard to develop a basic definition of "life" so that they knew what to look for on Mars. (4)

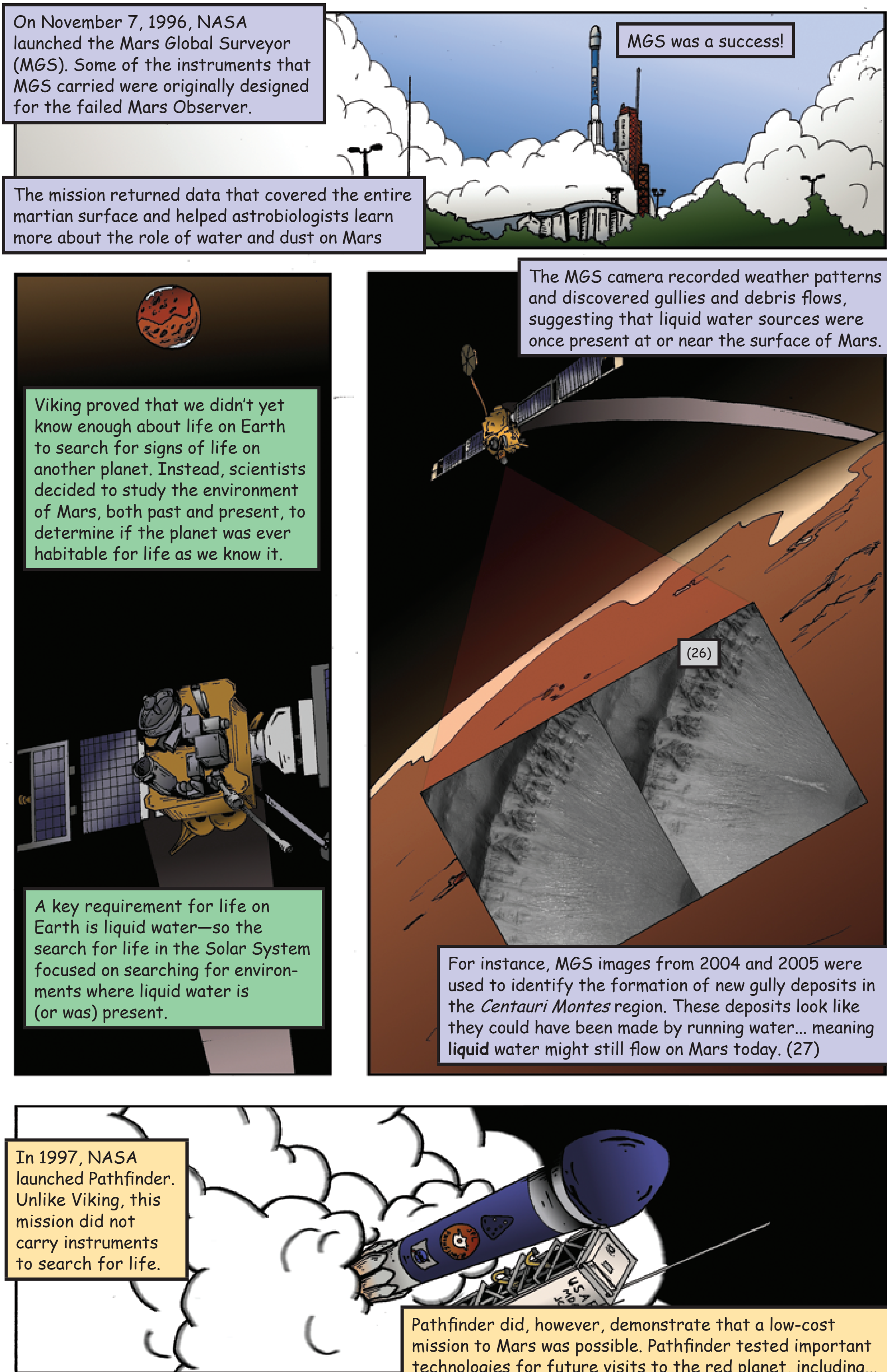

"The fact is that nothing we have learned about Mars—in contrast to Venus—excludes it as a possible abode of life...
...It is certainly true that no terrestrial species could survive under average martian conditions as we know them, except in a dormant state, but if we admit the possibility that Mars 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." (21)
"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." (21)
In December 1969, NASA selected experiments. They included Horowitz's pyrolytic release experiment, Levin's labeled release experiment, Vishniac's 'Wolf Trap' (later removed) and Oyama's gas exchange experiment.
The life detection experiments were fitted into a single package for the landers, which also carried miniaturized GC/MSs* to separate and identify organic compounds 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." (4)
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." (4)
*Gas Chromatograph/ Mass Spectrometers

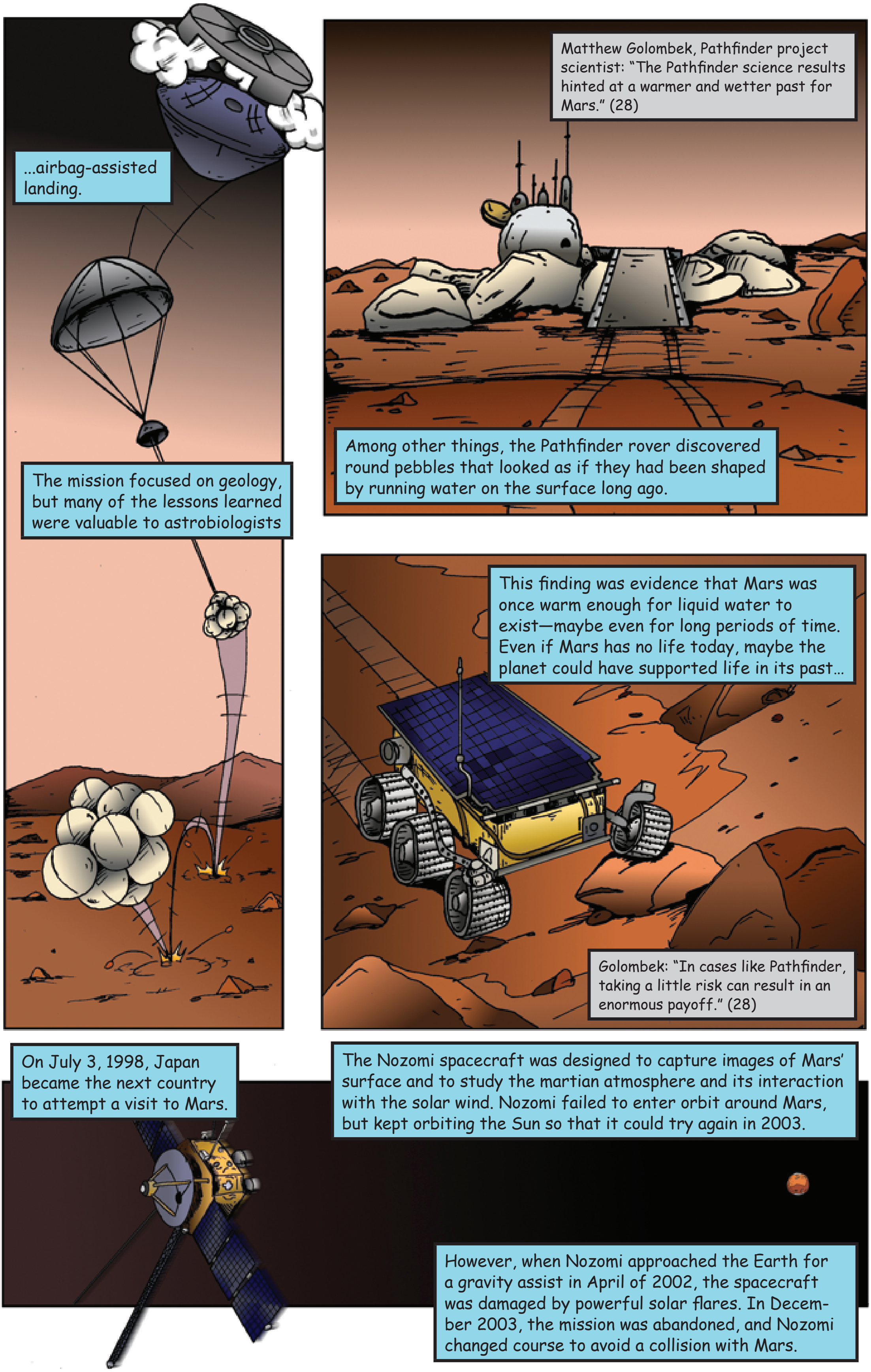


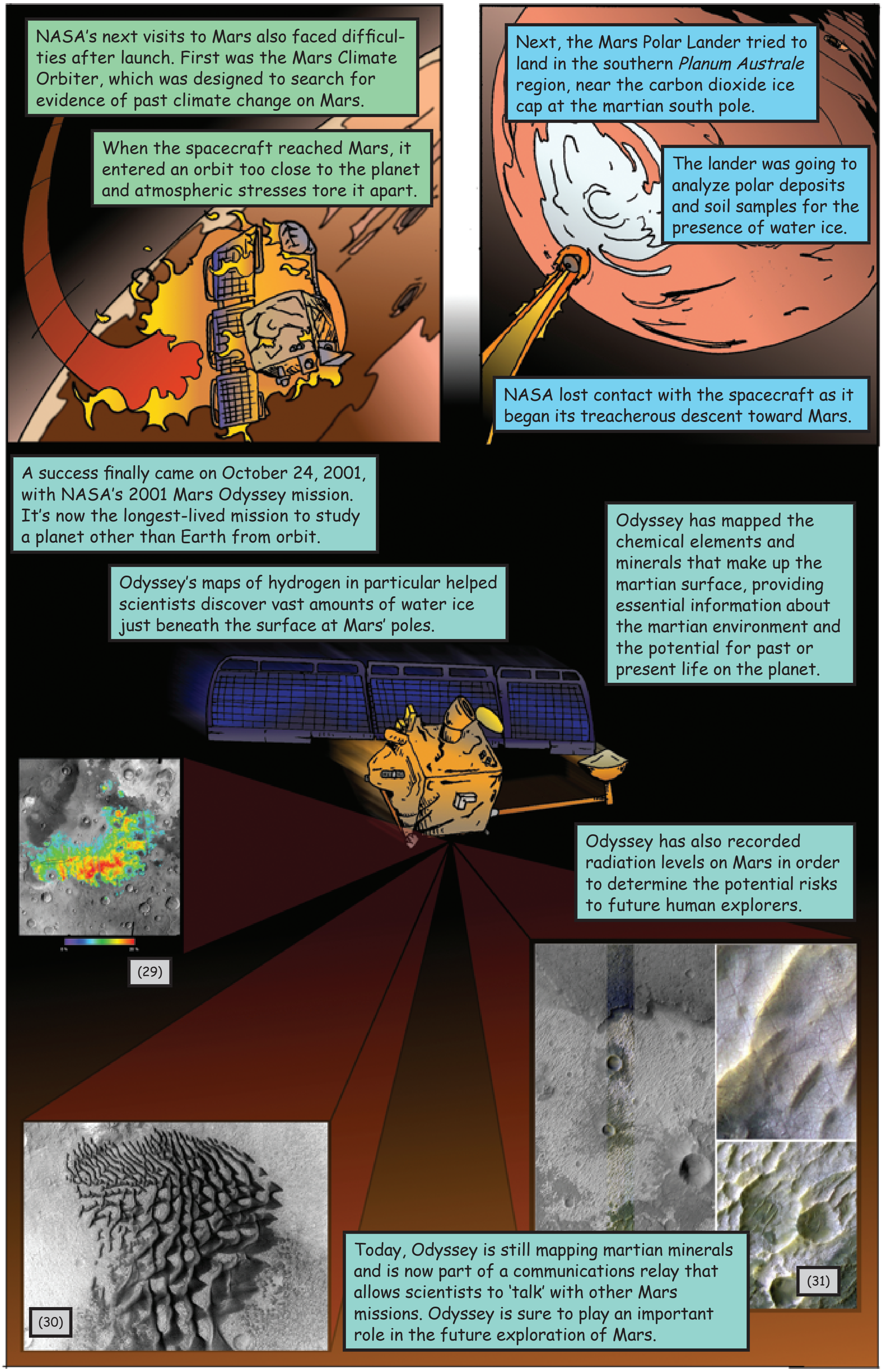
On July 20, 1976—seven years after the Apollo 11 lunar landing—the Viking 1 lander touched down on the flat, martian plain of *Chryse Planitia*.
To prevent contamination of Mars, the Viking Landers were assembled in a special clean room, baked in dry heat to kill any microorganisms, and kept in isolation 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 scooped samples into the instruments.
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..." (22)
"A new reality was created. Mars became a place. It went from a word, an abstract thought, to a real place." (4)
(23)
Thomas Mutch, head of the Viking surface photography team.
Gerald Soffen, Viking Project Manager

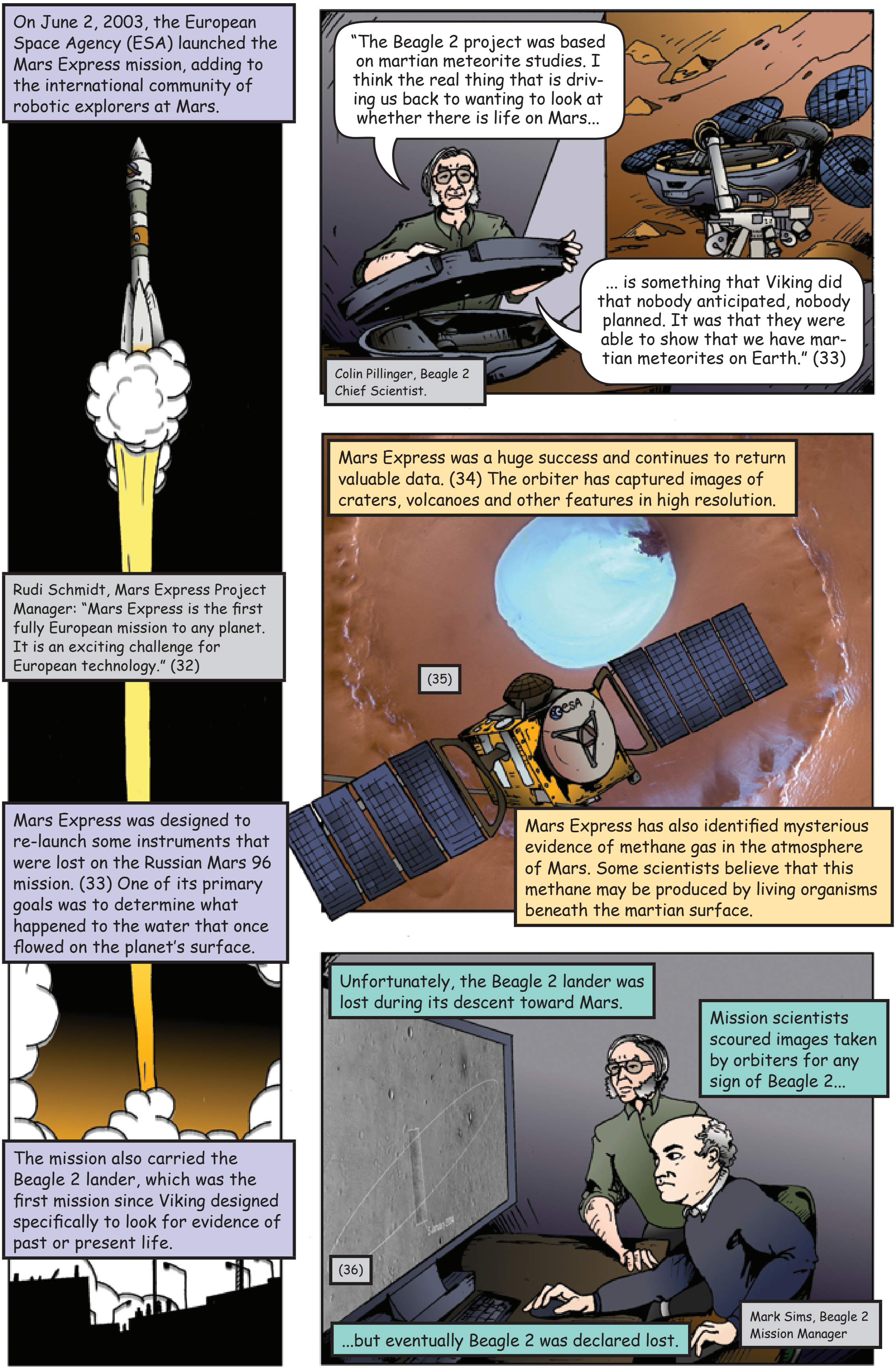

The labeled release experiment showed the strongest results, detecting CO_2 that might have been released by the metabolism of microorganisms. The GC/MS experiment, however, indicated that no organics were present on Mars.
The results were unexpected… and confusing.
"That's the ball game. No organics on Mars, no life on Mars." (4)
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." (4)
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, many scientists concluded that a chemical explanation for the results was the most likely. (24) 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." (4)
(25)

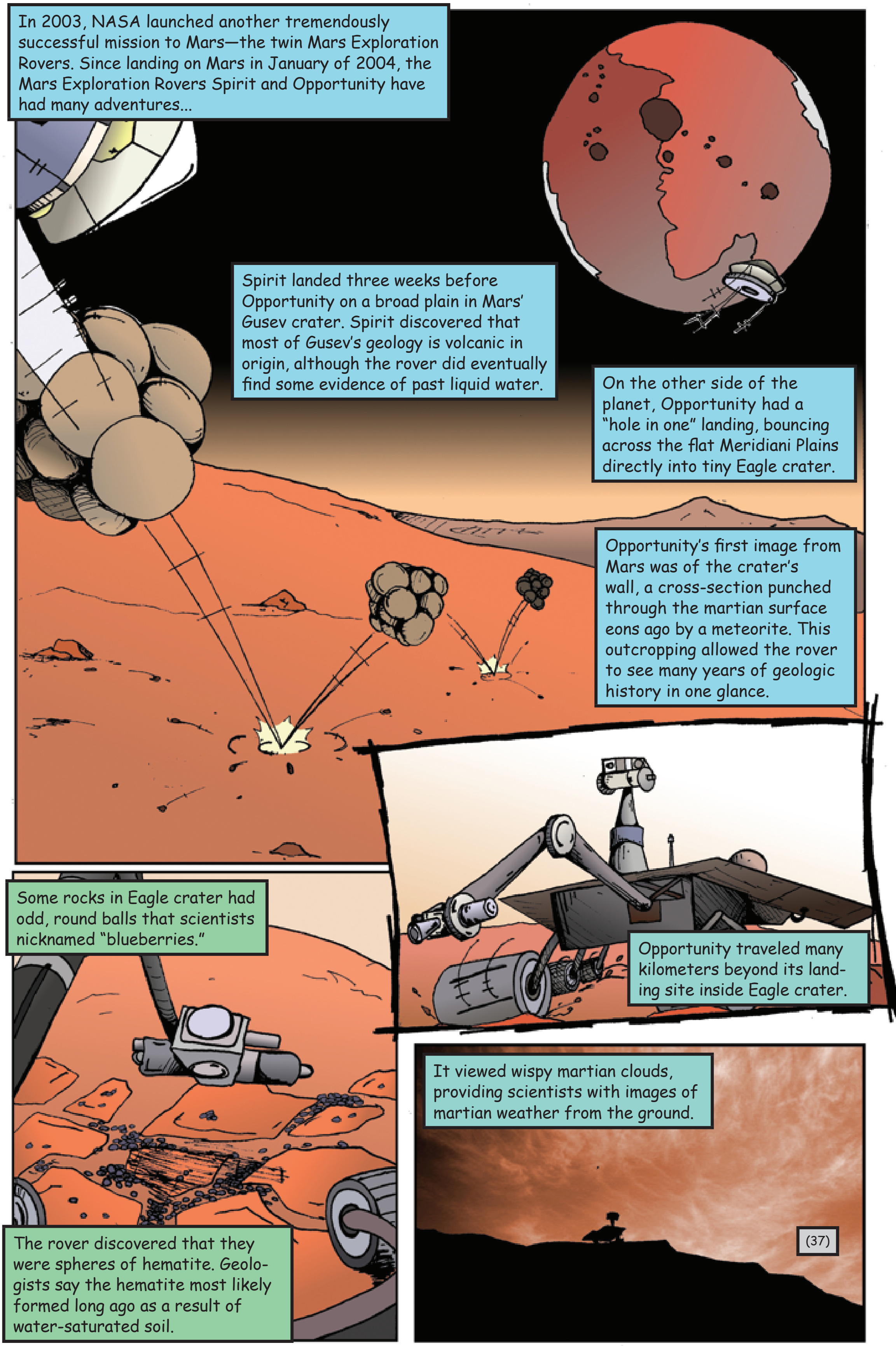

After all the time and effort spent on Viking, and with many questions left unanswered, where was Astrobiology headed?
"[Exobiology] was tied to the planetary missions. It hung on the Viking program." (4)
Viking didn't find unambiguous signs of life on Mars, but it made people wonder if we had devised the right tests. Astrobiologists today are still trying to answer this question...
In 1988, the Soviet Union (and international partners) launched Phobos 1 and 2. Only Phobos 2 made it, and gathered data about Mars' moon Phobos.
However, Phobos 2 fell silent...
...just before sending landers toward the moon.
After Phobos 2, Mars seemd to shroud itself in mystery.
Both the Soviet Union and the United States struggled with their missions.
In 1992, NASA launched the Mars Observer, but the spacecraft lost contact with Earth before entering Mars 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 was unsuccessful and Mars 96 burned up on re-entry into the Earth's atmosphere.

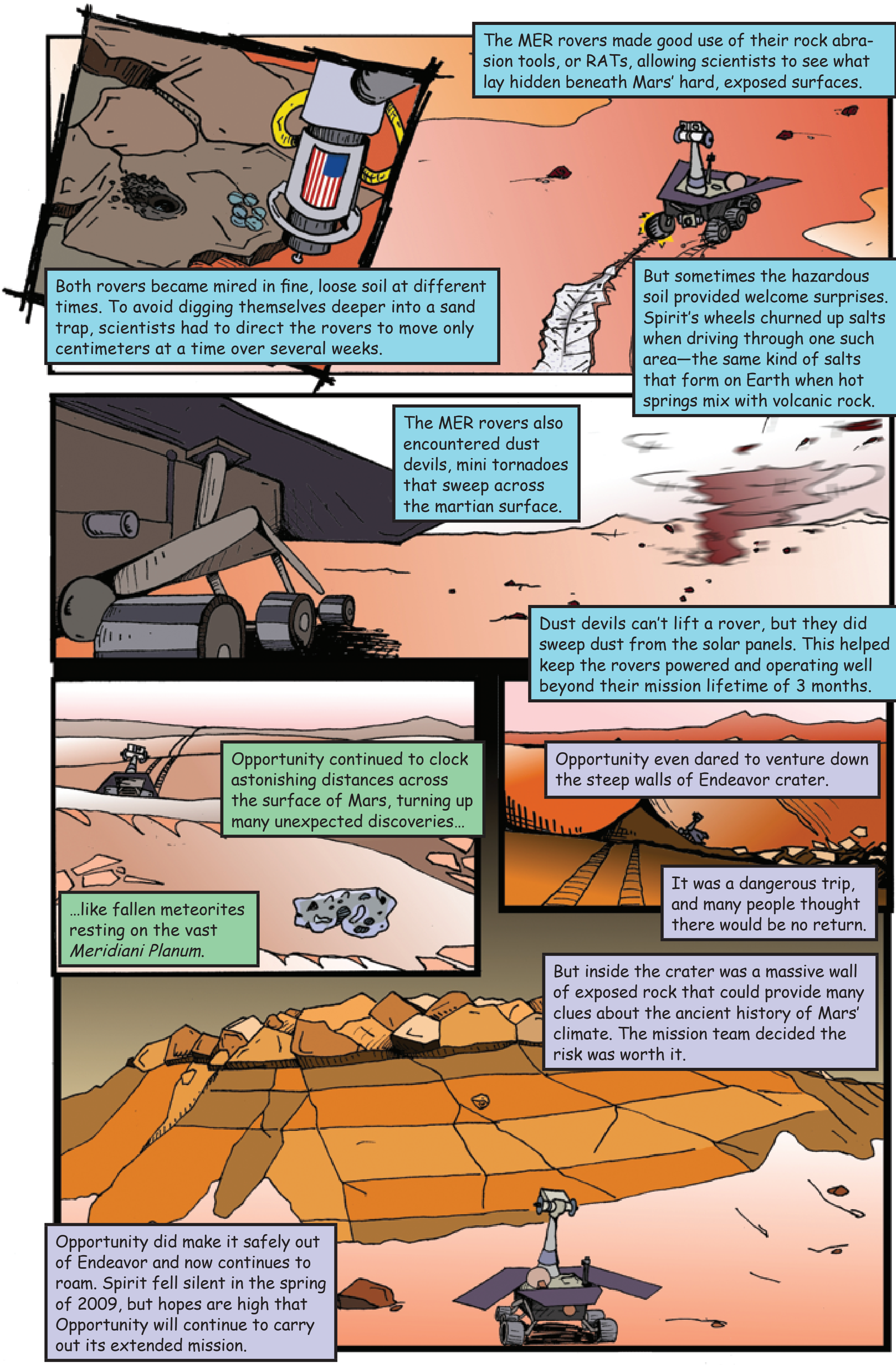

On November 7, 1996, NASA launched the Mars Global Surveyor (MGS). Some of the instruments that MGS carried were originally designed for the failed Mars Observer.
MGS was a success!
The mission returned data that covered the entire martian surface and helped astrobiologists learn more about the role of water and dust on Mars
Viking proved that we didn't yet know enough about life on Earth to search for signs of life on another planet. Instead, scientists decided to study the environment of Mars, both past and present, to determine if the planet was ever habitable 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 focused on searching for environments where liquid water is (or was) present.
The MGS camera recorded weather patterns and discovered gullies and debris flows, suggesting that liquid water sources were once present at or near the surface of Mars.
(26)
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. (27)
In 1997, NASA launched Pathfinder. 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...

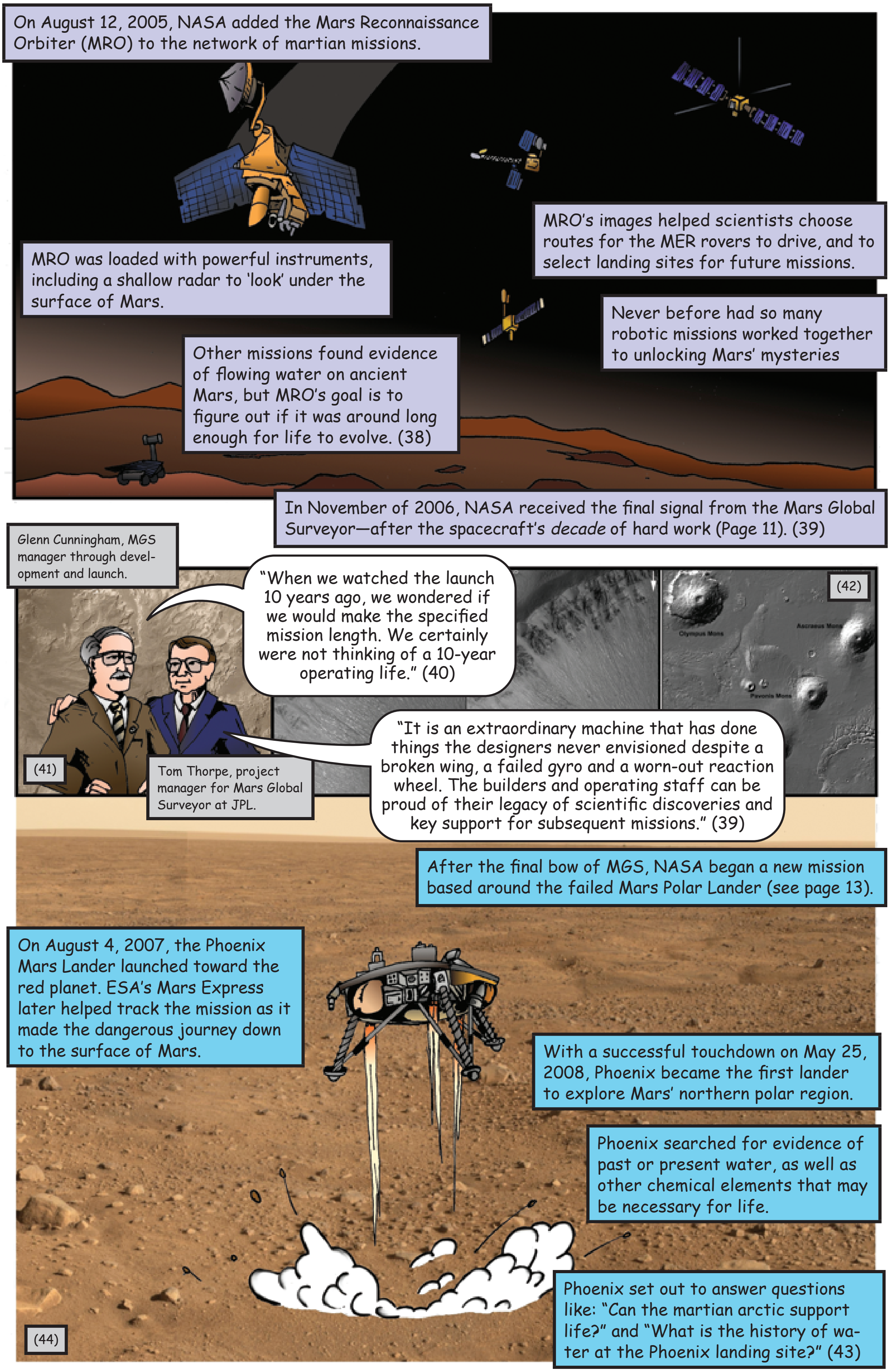

...airbag-assisted landing.
The mission focused on geology, but many of the lessons learned were valuable to astrobiologists
Matthew Golombek, Pathfinder project scientist: "The Pathfinder science results hinted at a warmer and wetter past for Mars." (28)
Among other things, the Pathfinder rover discovered 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." (28)
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 2003, the mission was abandoned, and Nozomi changed course to avoid a collision with Mars.

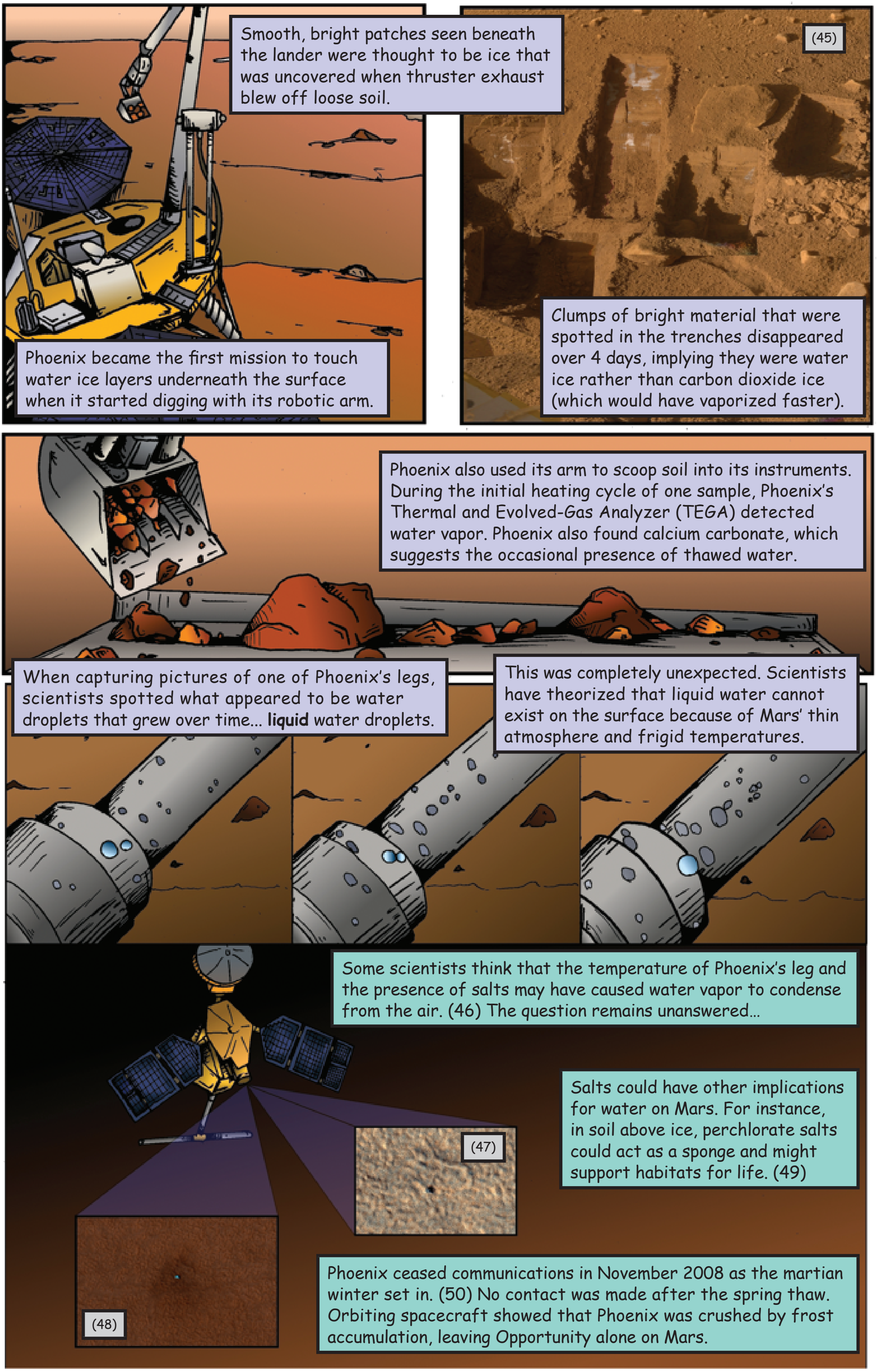

NASA's next visits to Mars also faced difficulties after launch. First was the Mars Climate Orbiter, which was designed to search for evidence of past climate change on Mars.
When the spacecraft reached Mars, it entered an orbit too close to the planet and atmospheric stresses tore it apart.
Next, the Mars Polar Lander tried 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.
A success finally came on October 24, 2001, with NASA's 2001 Mars Odyssey mission. It's now the longest-lived mission to study a planet other than Earth from orbit.
Odyssey's maps of hydrogen in particular helped scientists discover vast amounts of water ice just beneath the surface at Mars' poles.
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.
(29)
Odyssey has also recorded radiation levels on Mars in order to determine the potential risks to future human explorers.
(30)
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.
(31)

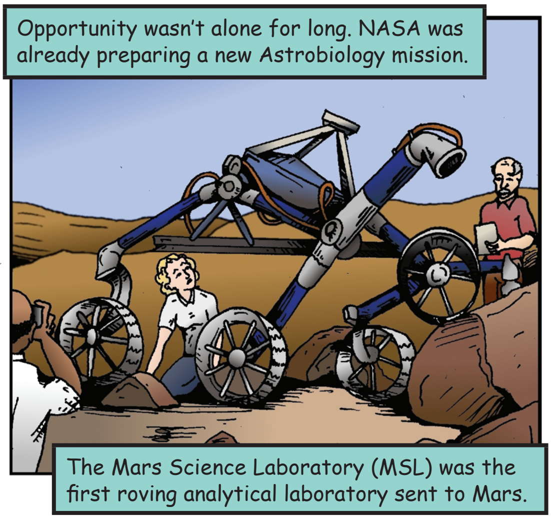

On June 2, 2003, the European Space Agency (ESA) launched the Mars Express mission, adding to the international community of robotic explorers at Mars.
Rudi Schmidt, Mars Express Project Manager: "Mars Express is the first fully European mission to any planet. It is an exciting challenge for European technology." (32)
Mars Express was designed to re-launch some instruments that were lost on the Russian Mars 96 mission. (33) 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.
"The Beagle 2 project was based on martian meteorite studies. I think the real thing that is driving us back to wanting to look at whether there is life on Mars...
... is something that Viking did that nobody anticipated, nobody planned. It was that they were able to show that we have martian meteorites on Earth." (33)
Colin Pillinger, Beagle 2 Chief Scientist.
Mars Express was a huge success and continues to return valuable data. (34) The orbiter has captured images of craters, volcanoes and other features in high resolution.
(35)
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.
Unfortunately, the Beagle 2 lander was lost during its descent toward Mars.
Mission scientists scoured images taken by orbiters for any sign of Beagle 2...
(36)
...but eventually Beagle 2 was declared lost.
Mark Sims, Beagle 2 Mission Manager

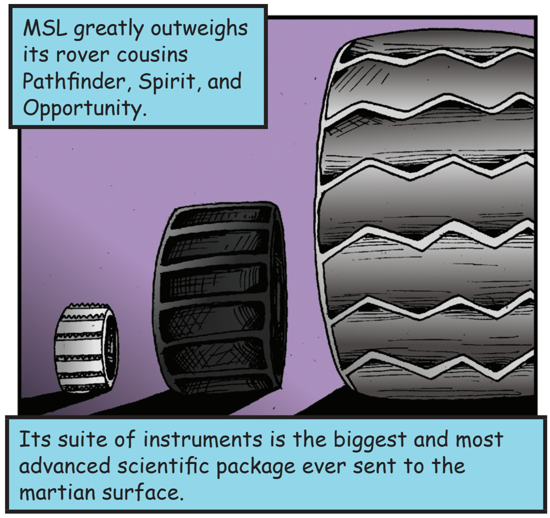

In 2003, NASA launched another tremendously successful mission to Mars—the twin Mars Exploration Rovers. Since landing on Mars in January of 2004, the Mars Exploration Rovers Spirit and Opportunity have had many adventures...
Spirit landed three weeks before Opportunity on a broad plain in Mars' Gusev 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.
Some rocks in Eagle crater had odd, round balls that scientists nicknamed "blueberries."
Opportunity traveled many kilometers beyond its landing site inside Eagle crater.
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.
(37)

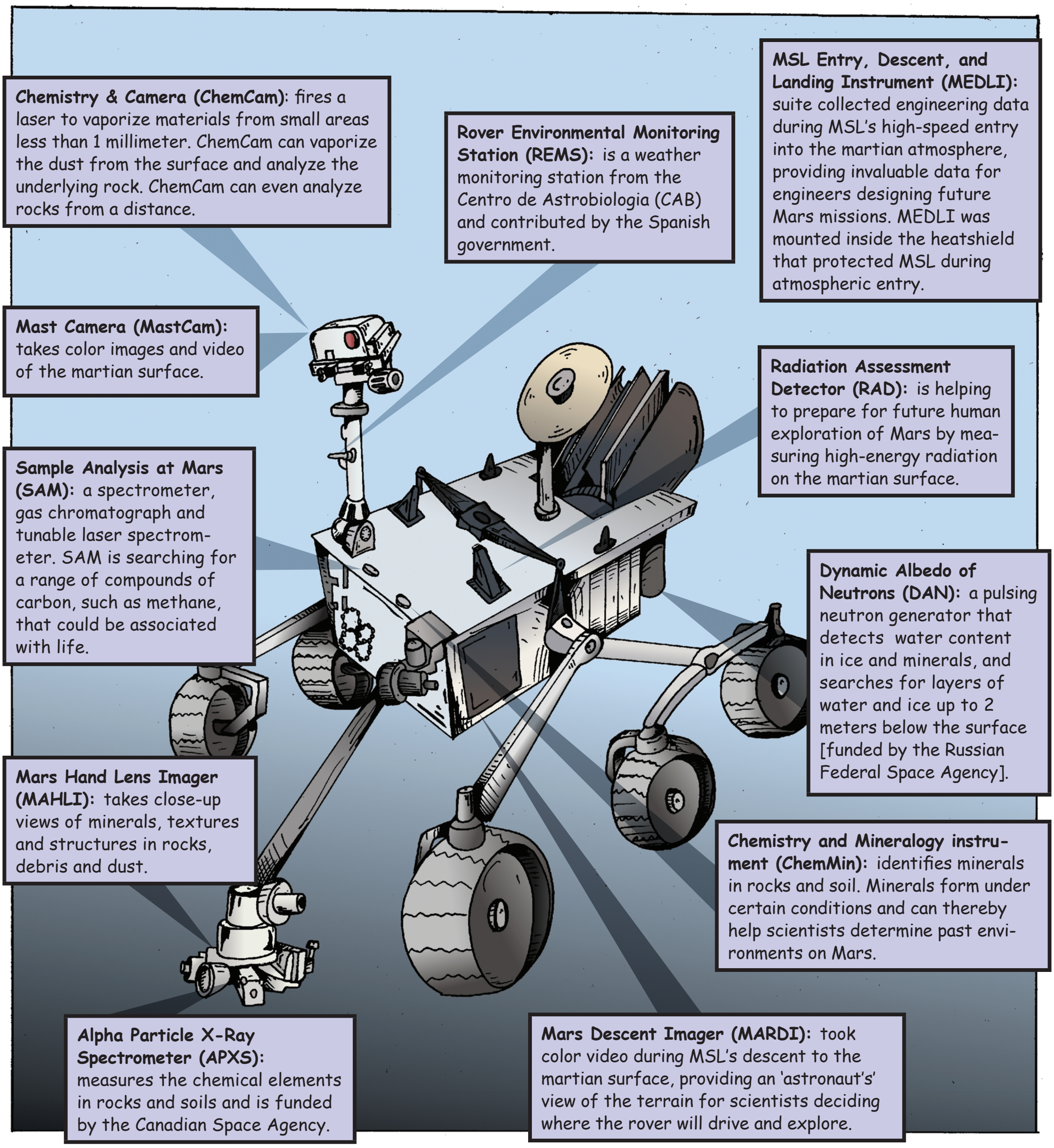

The MER rovers made good use of their rock abrasion tools, or RATs, allowing scientists to see what lay hidden beneath Mars' hard, exposed surfaces.
Both rovers became mired in fine, loose soil at different times. To avoid digging themselves deeper into a sand trap, scientists had to direct the rovers 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.
Dust devils can't lift a rover, but they did sweep dust from the solar panels. This helped keep the rovers powered and operating well beyond their mission lifetime of 3 months.
Opportunity continued to clock astonishing distances across the surface of Mars, turning up many unexpected discoveries...
...like 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.
Opportunity did make it safely out of Endeavor and now continues to roam. Spirit fell silent in the spring of 2009, but hopes are high that Opportunity will continue to carry out its extended mission.

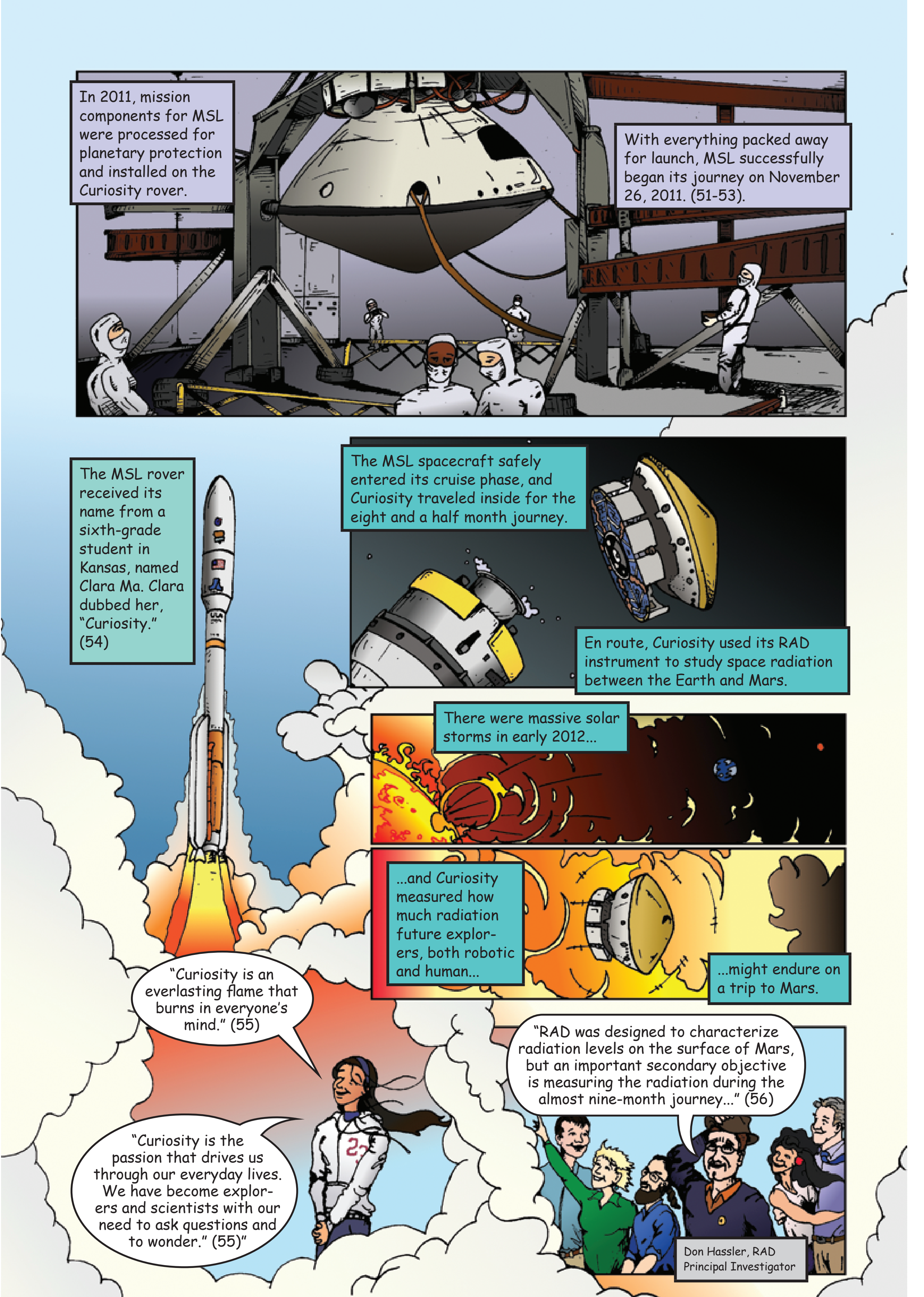

On August 12, 2005, NASA added the Mars Reconnaissance Orbiter (MRO) to the network of martian missions.
MRO's images helped scientists choose routes for the MER rovers to drive, and to select landing sites for future missions.
MRO was loaded with powerful instruments, including a shallow radar to 'look' under the surface of Mars.
Never before had so many robotic missions worked together to unlocking Mars' mysteries
Other missions found evidence of flowing water on ancient Mars, but MRO's goal is to figure out if it was around long enough for life to evolve. (38)
In November of 2006, NASA received the final signal from the Mars Global Surveyor—after the spacecraft's *decade* of hard work (Page 11). (39)
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." (40)
(42)
(41)
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." (39)
After the final bow of MGS, NASA began a new mission 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.
Phoenix searched for evidence of past or present water, as well as other chemical elements that may be necessary for life.
(44)
Phoenix set out to answer questions like: "Can the martian arctic support life?" and "What is the history of water at the Phoenix landing site?" (43)


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.
(45)
Clumps of bright material that were spotted in the trenches 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 into 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. Scientists have theorized 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. (46) The question remains unanswered...
Salts could have other implications for water on Mars. For instance, in soil above ice, perchlorate salts could act as a sponge and might support habitats for life. (49)
(47)
(48)
Phoenix ceased communications in November 2008 as the martian winter set in. (50) No contact was made after the spring thaw. Orbiting spacecraft showed that Phoenix was crushed by frost accumulation, leaving Opportunity alone on Mars.

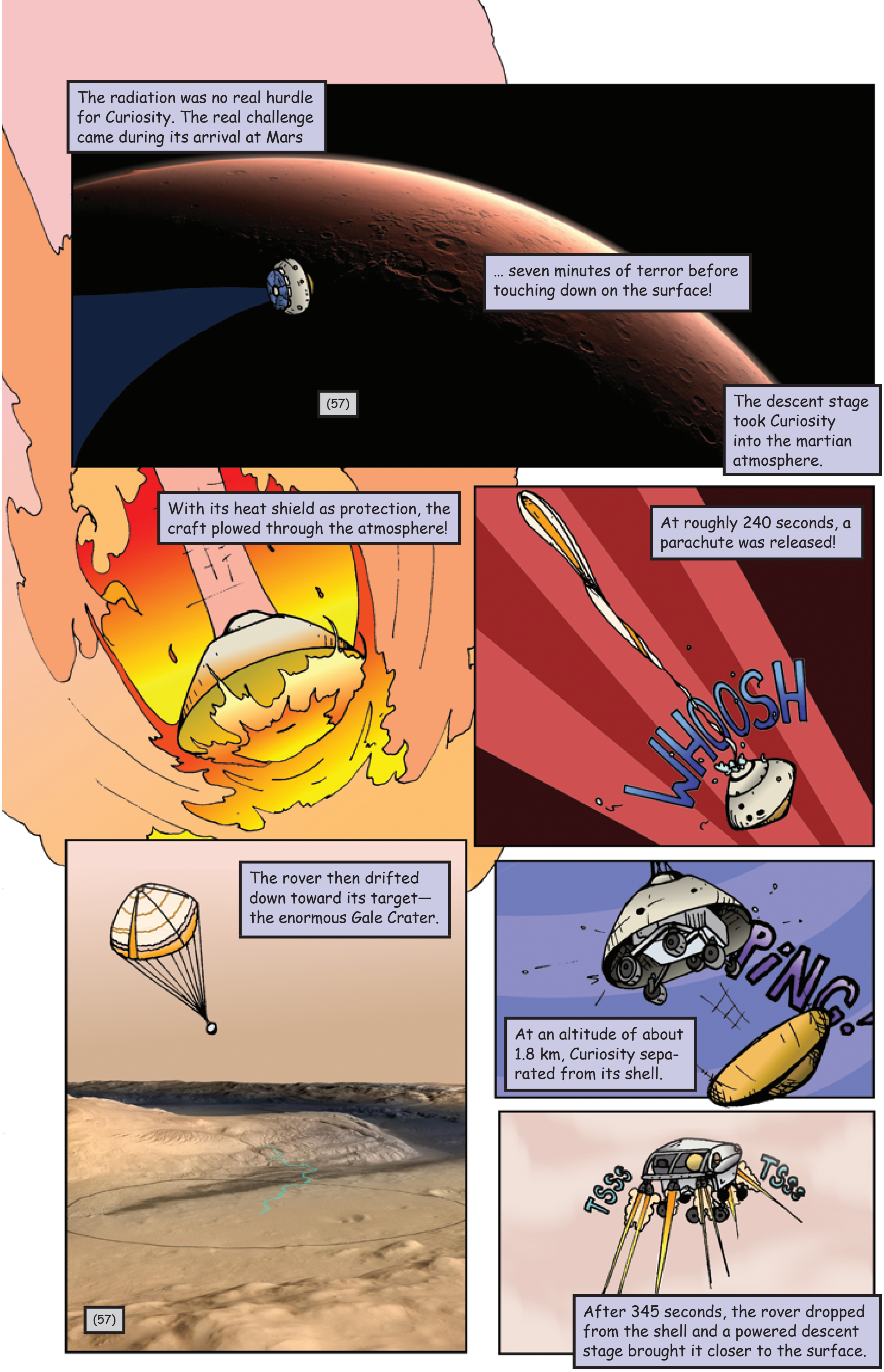

Opportunity wasn't alone for long. NASA was already preparing a new Astrobiology mission.
The Mars Science Laboratory (MSL) was the first roving analytical laboratory sent to Mars.

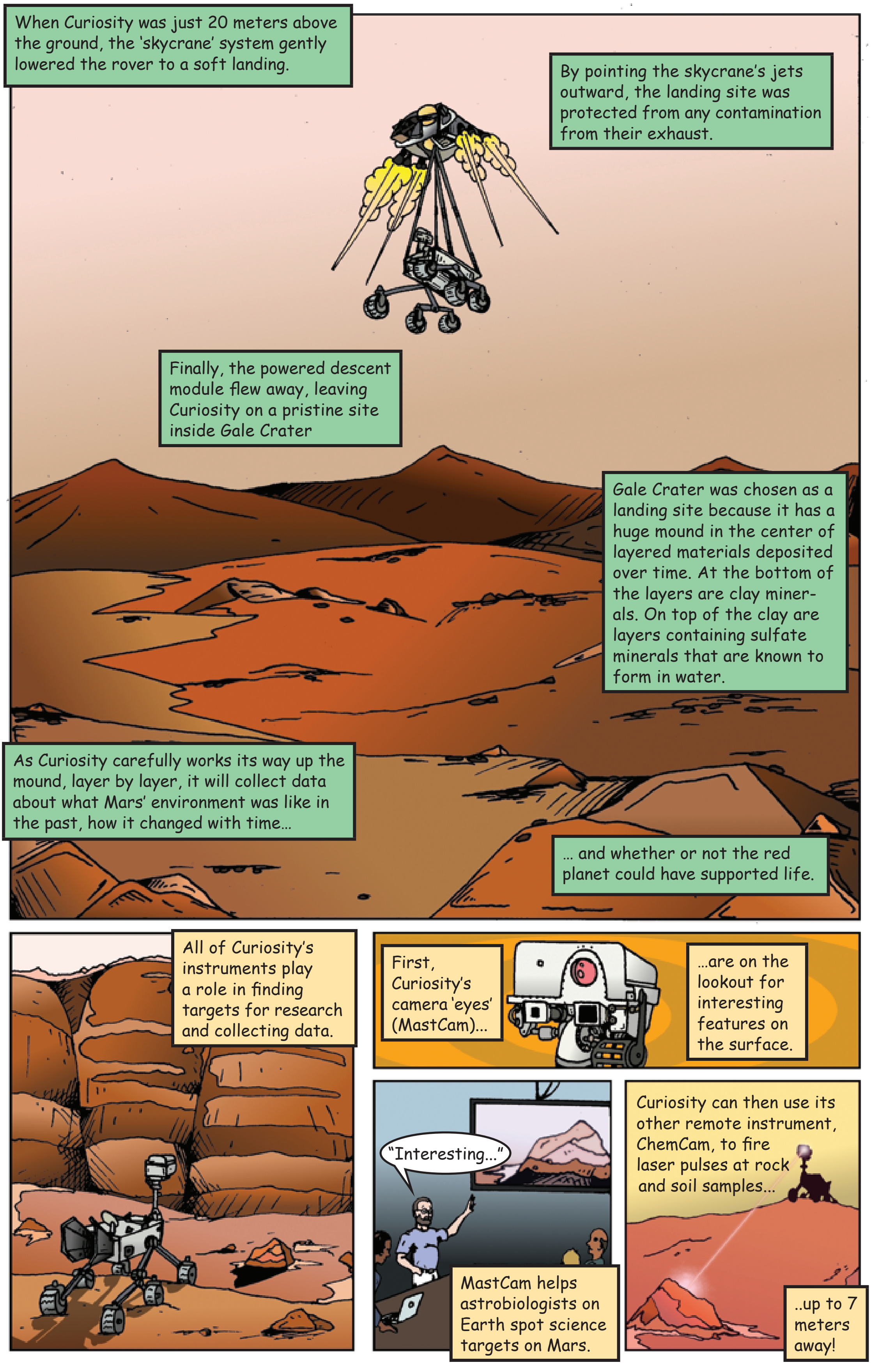

MSL greatly outweighs its rover cousins Pathfinder, Spirit, and Opportunity.
Its suite of instruments is the biggest and most advanced scientific package ever sent to the martian surface.


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): is a weather monitoring station from the Centro de Astrobiologia (CAB) and contributed by the Spanish government.
MSL Entry, Descent, and Landing Instrument (MEDLI): suite collected engineering data during MSL's high-speed entry into the martian atmosphere, providing invaluable data for engineers designing future Mars missions. MEDLI was mounted inside the heatshield that protected MSL during atmospheric entry.
Mast Camera (MastCam): takes color images and video of the martian surface.
Radiation Assessment Detector (RAD): is helping to prepare for future human exploration of Mars by measuring high-energy radiation on the martian surface.
Sample Analysis at Mars (SAM): a spectrometer, gas chromatograph and tunable laser spectrometer. SAM is searching for a range of compounds of carbon, such as methane, that could be associated with life.
Dynamic Albedo of Neutrons (DAN): a pulsing neutron generator that detects water content in ice and minerals, and searches for layers of water and ice up to 2 meters below the surface [funded by the Russian Federal Space Agency].
Mars Hand Lens Imager (MAHLI): takes close-up views of minerals, textures and structures in rocks, debris and dust.
Chemistry and Mineralogy instrument (ChemMin): identifies 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): measures the chemical elements in rocks and soils and is funded by the Canadian Space Agency.
Mars Descent Imager (MARDI): took 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.

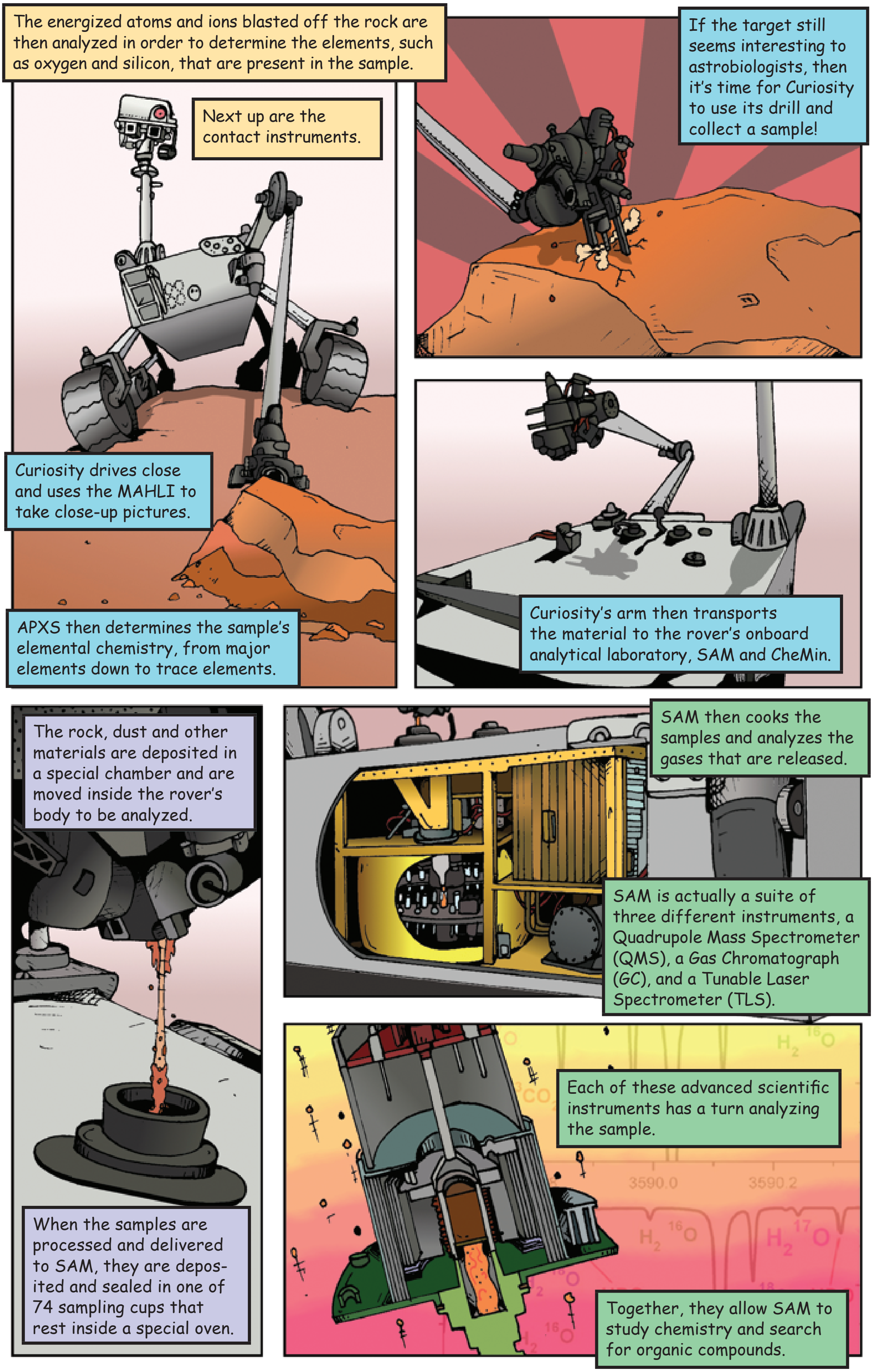


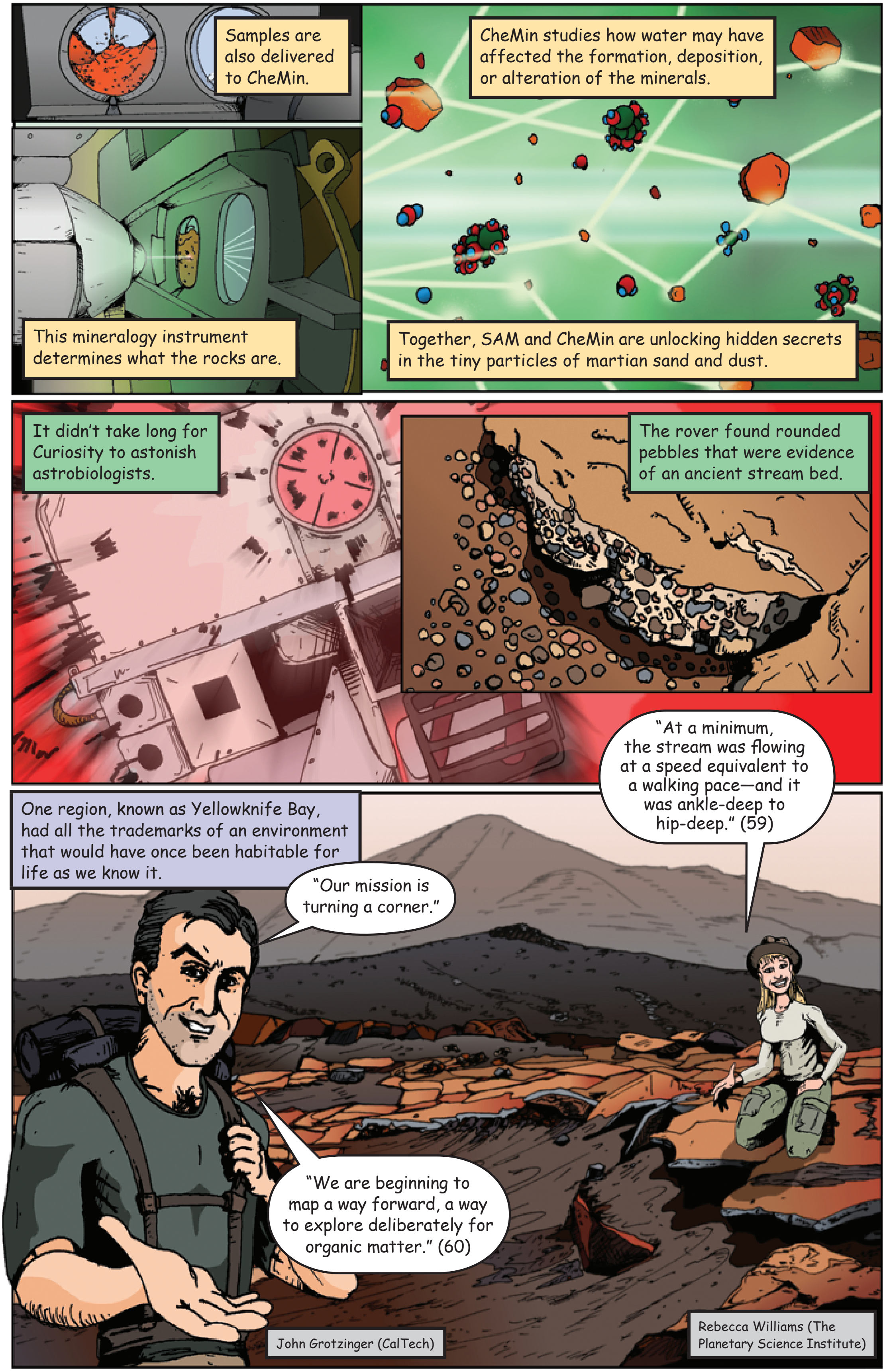
In 2011, mission components for MSL were processed for planetary protection and installed on the Curiosity rover.
With everything packed away for launch, MSL successfully began its journey on November 26, 2011. (51-53).
The MSL rover received its name from a sixth-grade student in Kansas, named Clara Ma. Clara dubbed her, "Curiosity." (54)
The MSL spacecraft safely entered its cruise phase, and Curiosity traveled inside for the eight and a half month journey.
En route, Curiosity used its RAD instrument to study space radiation between the Earth and Mars.
There were massive solar storms in early 2012...
...and Curiosity measured how much radiation future explor-ers, both robotic and human...
...might endure on a trip to Mars.
"Curiosity is an everlasting flame that burns in everyone's mind." (55)
"Curiosity is the passion that drives us through our everyday lives. We have become explor-ers and scientists with our need to ask questions and to wonder." (55)"
"RAD was designed to characterize radiation levels on the surface of Mars, but an important secondary objective is measuring the radiation during the almost nine-month journey..." (56)
Don Hassler, RAD Principal Investigator

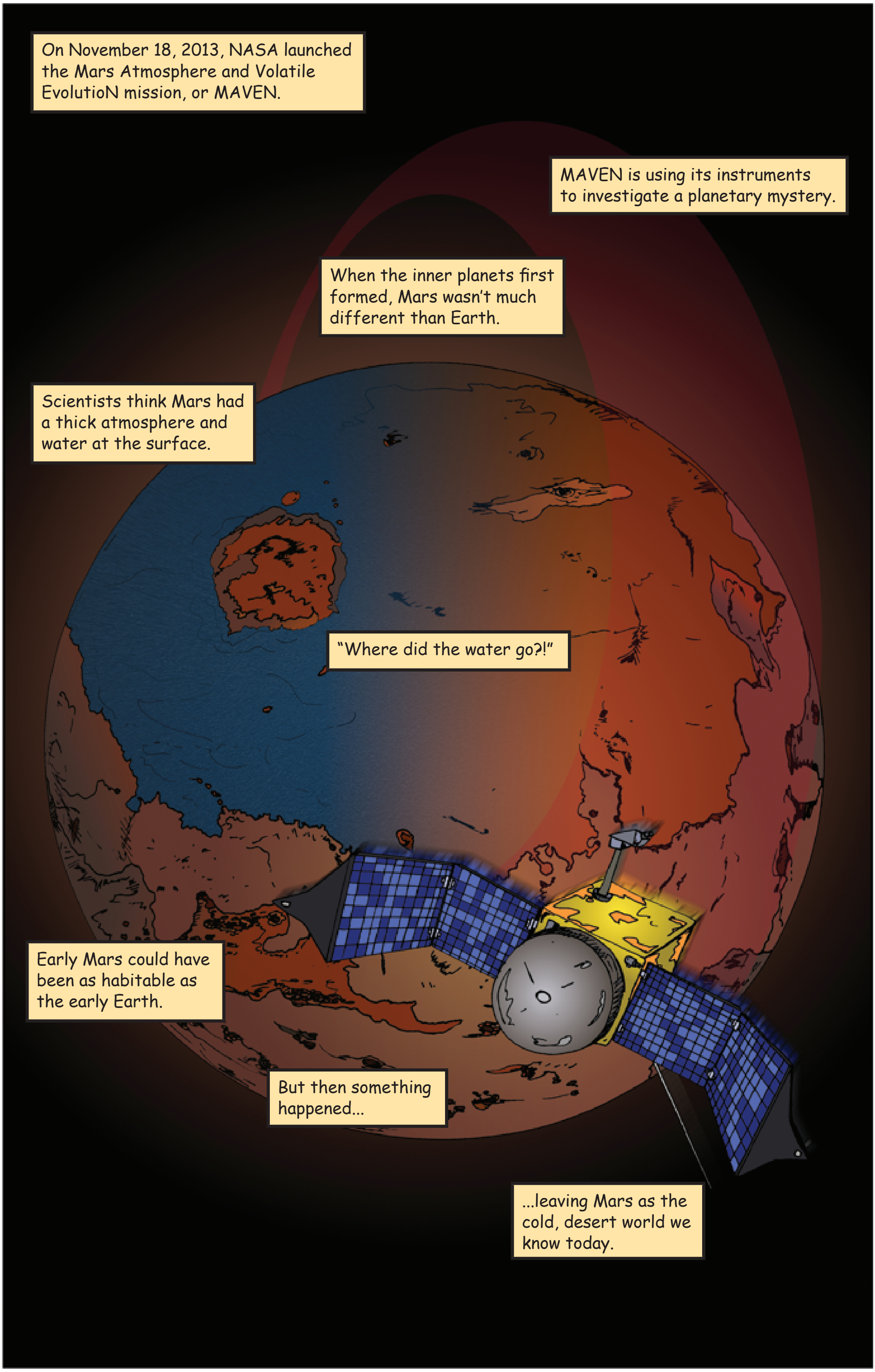

The radiation was no real hurdle for Curiosity. The real challenge came during its arrival at Mars
... seven minutes of terror before touching down on the surface!
(57)
The descent stage took Curiosity into the martian atmosphere.
With its heat shield as protection, the craft plowed through the atmosphere!
At roughly 240 seconds, a parachute was released!
WHOOSH
The rover then drifted down toward its target—the enormous Gale Crater.
(57)
PiNG!
At an altitude of about 1.8 km, Curiosity separated from its shell.
TSSS
TSSS
After 345 seconds, the rover dropped from the shell and a powered descent stage brought it closer to the surface.

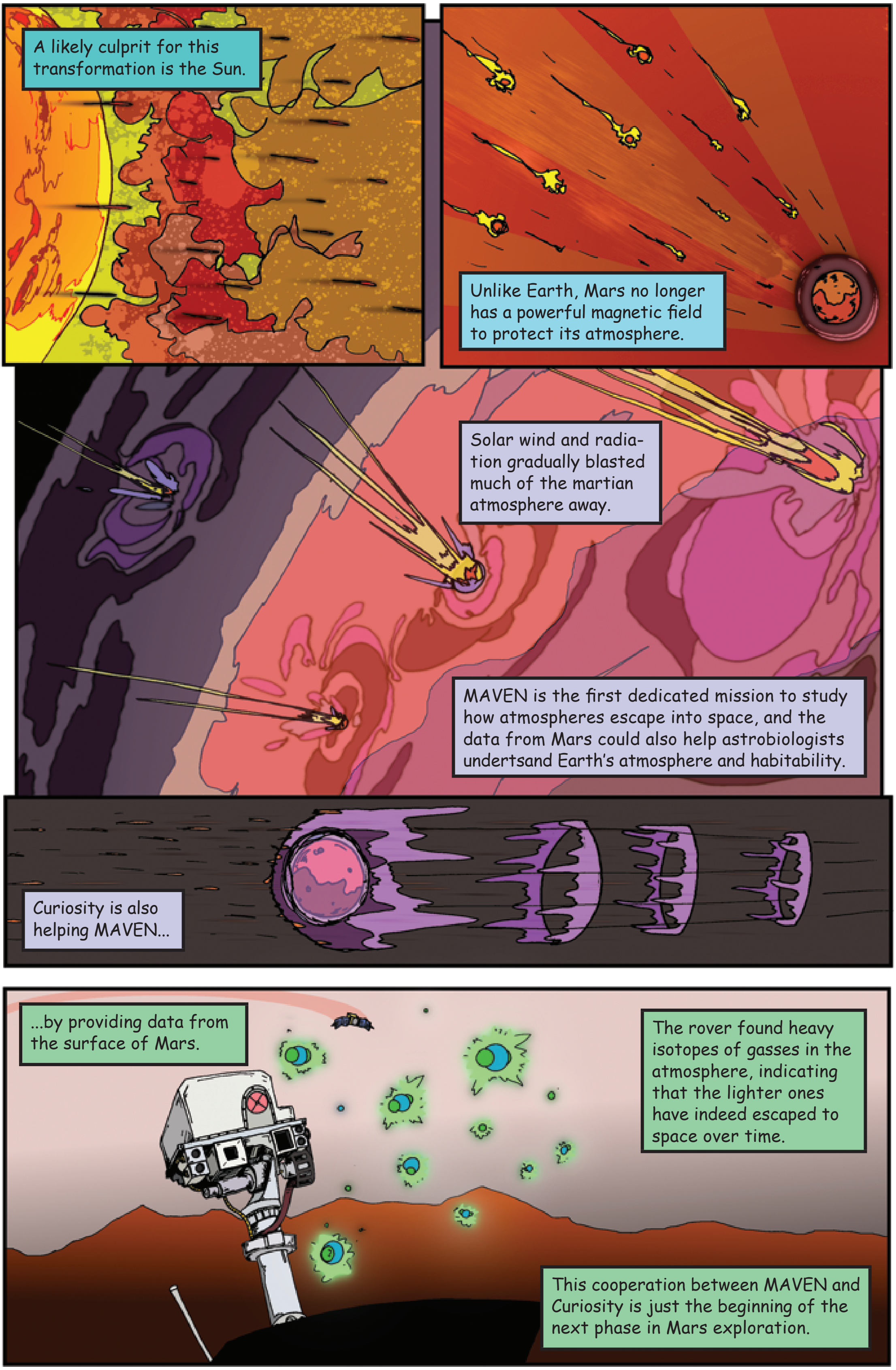


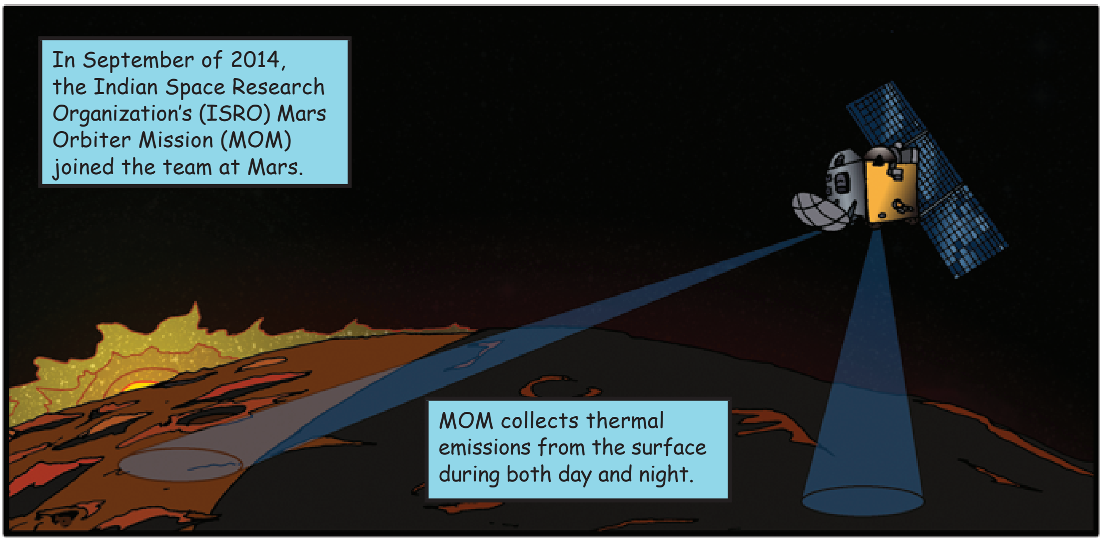
When Curiosity was just 20 meters above the ground, the 'skycrane' system gently lowered the rover to a soft landing.
By pointing the skycrane's jets outward, the landing site was protected from any contamination from their exhaust.
Finally, the powered descent module flew away, leaving Curiosity on a pristine site inside Gale Crater
Gale Crater was chosen as a landing site because it has a huge mound in the center of layered materials deposited over time. At the bottom of the layers are clay miner-als. On top of the clay are layers containing sulfate minerals that are known to form in water.
As Curiosity carefully works its way up the mound, layer by layer, it will collect data about what Mars' environment was like in the past, how it changed with time...
... and whether or not the red planet could have supported life.
All of Curiosity's instruments play a role in finding targets for research and collecting data.
First, Curiosity's camera 'eyes' (MastCam)...
...are on the lookout for interesting features on the surface.
"Interesting..."
MastCam helps astrobiologists on Earth spot science targets on Mars.
Curiosity can then use its other remote instrument, ChemCam, to fire laser pulses at rock and soil samples...
..up to 7 meters away!

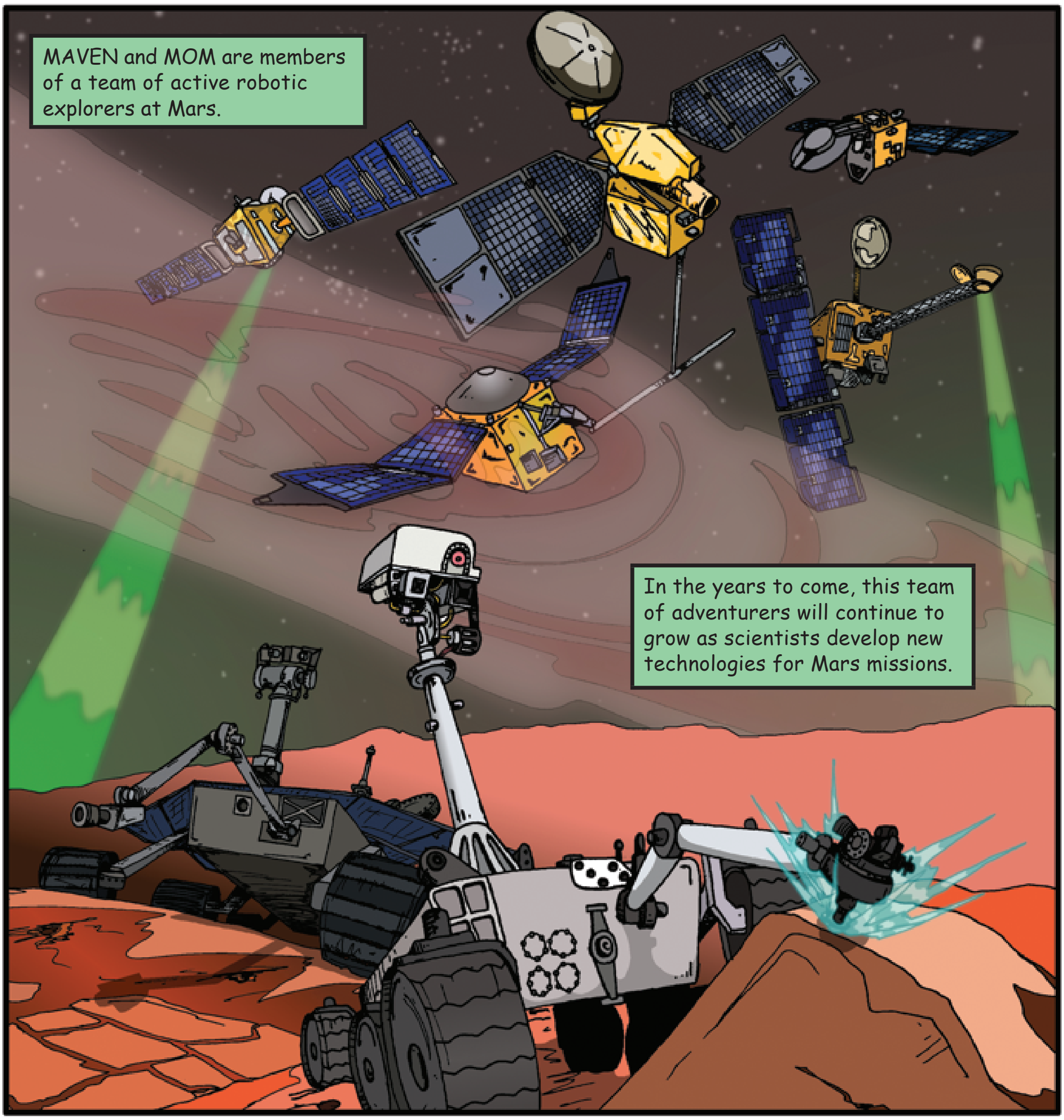

The energized atoms and ions blasted off the rock are then analyzed in order to determine the elements, such as oxygen and silicon, that are present in the sample.
Next up are the contact instruments.
Curiosity drives close and uses the MAHLI to take close-up pictures.
APXS then determines the sample's elemental chemistry, from major elements down to trace elements.
If the target still seems interesting to astrobiologists, then it's time for Curiosity to use its drill and collect a sample!
Curiosity's arm then transports the material to the rover's onboard analytical laboratory, SAM and CheMin.
The rock, dust and other materials are deposited in a special chamber and are moved inside the rover's body to be analyzed.
When the samples are processed and delivered to SAM, they are deposited and sealed in one of 74 sampling cups that rest inside a special oven.
SAM then cooks the samples and analyzes the gases that are released.
SAM is actually a suite of three different instruments, a Quadrupole Mass Spectrometer (QMS), a Gas Chromatograph (GC), and a Tunable Laser Spectrometer (TLS).
Each of these advanced scientific instruments has a turn analyzing the sample.
3590.0
3590.2
Together, they allow SAM to study chemistry and search for organic compounds.

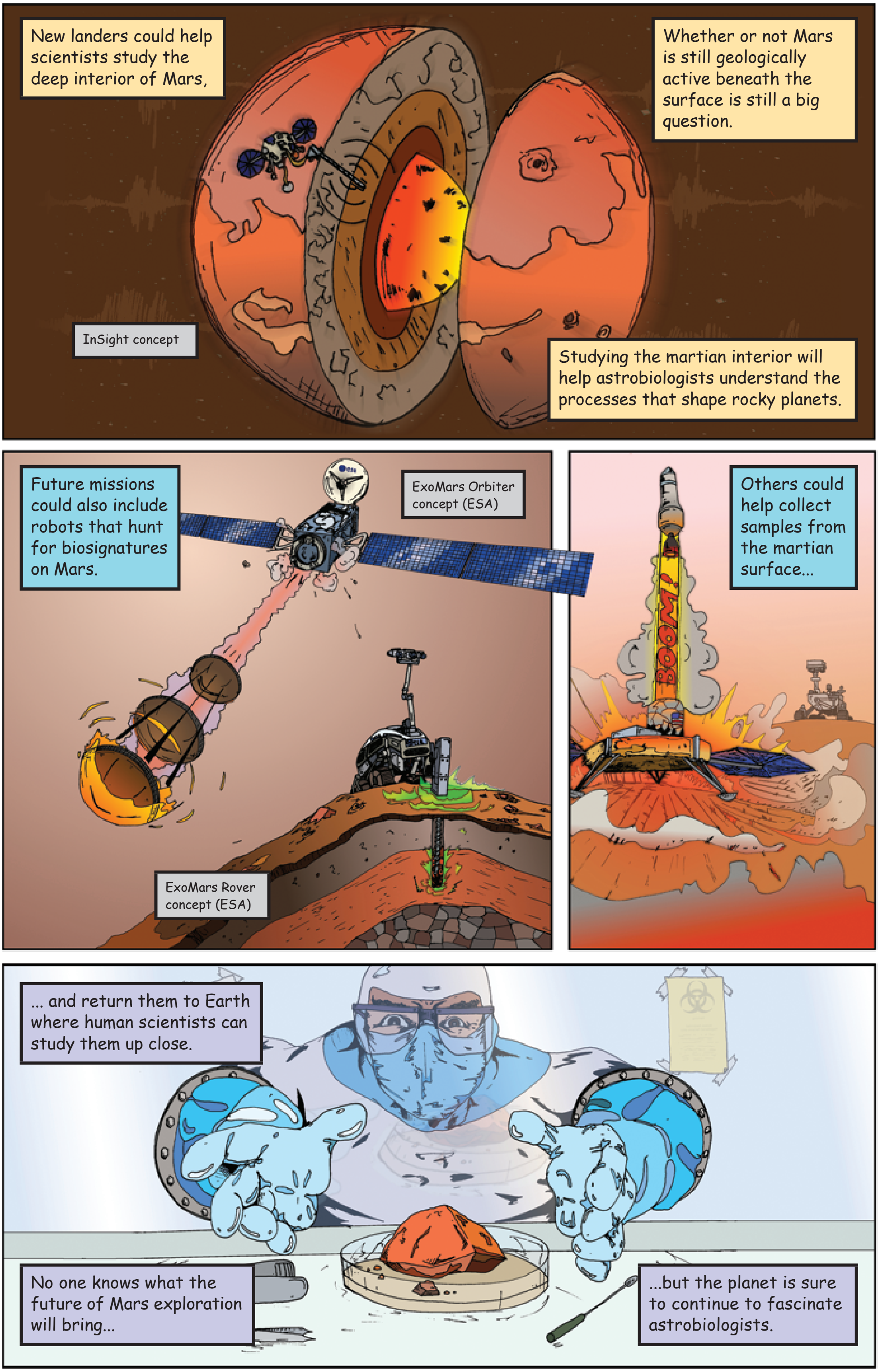

Samples are also delivered to CheMin.
This mineralogy instrument determines what the rocks are.
CheMin studies how water may have affected the formation, deposition, or alteration of the minerals.
Together, SAM and CheMin are unlocking hidden secrets in the tiny particles of martian sand and dust.
It didn't take long for Curiosity to astonish astrobiologists.
The rover found rounded pebbles that were evidence of an ancient stream bed.
One region, known as Yellowknife Bay, had all the trademarks of an environment that would have once been habitable for life as we know it.
"Our mission is turning a corner."
"We are beginning to map a way forward, a way to explore deliberately for organic matter." (60)
"At a minimum, the stream was flowing at a speed equivalent to a walking pace—and it was ankle-deep to hip-deep." (59)
John Grotzinger (CalTech)
Rebecca Williams (The Planetary Science Institute)

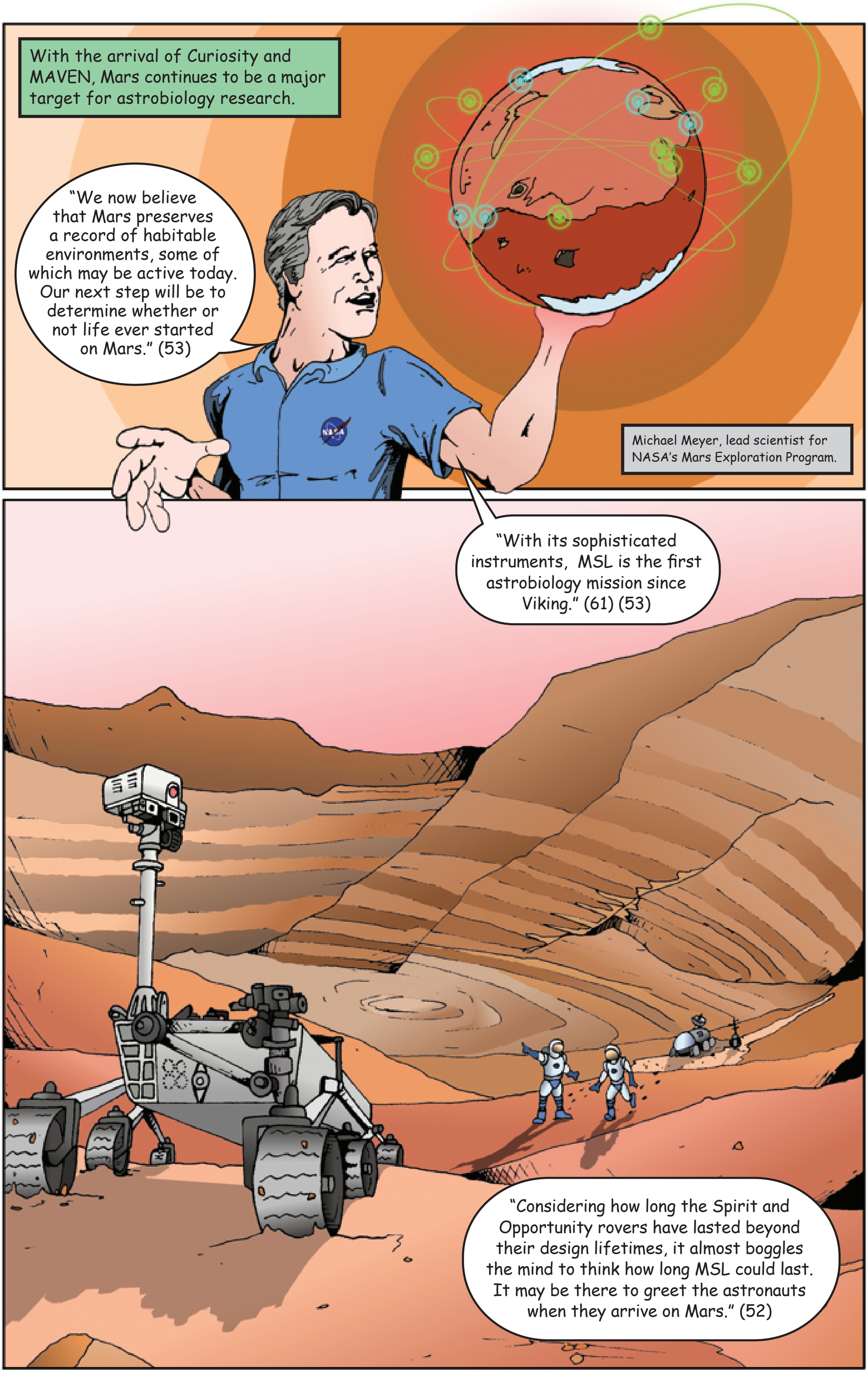

On November 18, 2013, NASA launched the Mars Atmosphere and Volatile EvolutioN mission, or MAVEN.
MAVEN is using its instruments to investigate a planetary mystery.
When the inner planets first formed, Mars wasn't much different than Earth.
Scientists think Mars had a thick atmosphere and water at the surface.
"Where did the water go?!"
Early Mars could have been as habitable as the early Earth.
But then something happened...
...leaving Mars as the cold, desert world we know today.


A likely culprit for this transformation is the Sun.
Unlike Earth, Mars no longer has a powerful magnetic field to protect its atmosphere.
Solar wind and radiation gradually blasted much of the martian atmosphere away.
MAVEN is the first dedicated mission to study how atmospheres escape into space, and the data from Mars could also help astrobiologists undertsand Earth's atmosphere and habitability.
Curiosity is also helping MAVEN...
...by providing data from the surface of Mars.
The rover found heavy isotopes of gasses in the atmosphere, indicating that the lighter ones have indeed escaped to space over time.
This cooperation between MAVEN and Curiosity is just the beginning of the next phase in Mars exploration.


In September of 2014, the Indian Space Research Organization's (ISRO) Mars Orbiter Mission (MOM) joined the team at Mars.
MOM collects thermal emissions from the surface during both day and night.


MAVEN and MOM are members of a team of active robotic explorers at Mars.
In the years to come, this team of adventurers will continue to grow as scientists develop new technologies for Mars missions.


New landers could help scientists study the deep interior of Mars,
Whether or not Mars is still geologically active beneath the surface is still a big question.
InSight concept
Studying the martian interior will help astrobiologists understand the processes that shape rocky planets.
Future missions could also include robots that hunt for biosignatures on Mars.
ExoMars Orbiter concept (ESA)
ExoMars Rover concept (ESA)
Others could help collect samples from the martian surface...
BOOM!
... and return them to Earth where human scientists can study them up close.
No one knows what the future of Mars exploration will bring...
...but the planet is sure to continue to fascinate astrobiologists.


With the arrival of Curiosity and MAVEN, Mars continues to be a major target for astrobiology research.
"We now believe that Mars preserves a record of habitable environments, some of which may be active today. Our next step will be to determine whether or not life ever started on Mars." (53)
Michael Meyer, lead scientist for NASA's Mars Exploration Program.
"With its sophisticated instruments, MSL is the first astrobiology mission since Viking." (61) (53)
"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." (52)

Further Resources and References cited in this issue:

1. The background on this page is an image of M72: A globular cluster of stars captured by the Hubble Space Telescope. M72 is 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
2. Harold "Chuck" Klein (First head of the Exobiology Division, NASA Ames Research Center)
3. L.P. "Pete" Zill (third head of Exobiology at NASA Ames)
4. Dick, S.J., and Strick, J.E. (2005) *The Living Universe: NASA and the development of Astrobiology*. Rutgers University Press, New Brunswick, New Jersey, and London.
5. Richard "Dick" Young (second head of Exobiology at NASA Ames; first head of the Exobiology Program at NASA Headquarters)
6. Vance Oyama, NASA Ames biologist.
7. Cyril Ponnamperuma (Arrived at NASA Ames in the first class of postdoctoral fellows (summer 1961) (8)
8. Bugos, Glenn E. 1999. *Atmosphere of Freedom—Sixty Years At The NASA Ames Research Center*. NASA SP-4314. p77-80.3.
9. Armagnac, A.P. (1962) Will Mariner solve these mysteries of Venus? Popular Science, Vol. 181, No. 6, 204p.
10. BBC News. 1962. 'Music of spheres' hails Venus fly-by. BBC News. Archive available at: http://news.bbc.co.uk/onthisday/hi/dates/stories/december/14/ newsid_4061000/4061955.stm
11. Mariner 4 image, the first close-up image ever taken of Mars. The image is centered at 37oN, 187oW and is roughly 330 kilometers (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
12. 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 14oS, 174oW. North is at roughly 11:00 in this image. Credit: NASA
13. 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 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
14. The cratered surface of Mars taken by Mariner 6. Image Credit: NASA/JPL
15. Mariner 7 had its closest approach to Mars at a distance of 3,524 km on July 31, 1969; after Mariner 6's flyby. Image Credit: NASA/JPL
16. 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 6oS, 105oW, at the edge of the Tharsis bulge. North is up. (Mariner 9, MTVS 4187-45). Credit: NASA/JPL
17. Mariner 9 image of the north polar cap of Mars. The image was taken on

October 12, 1972, about one-half martian month after summer solstice. At this 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 89oN, 200oW. (Mariner 9, MTVS 4297-47). Credit: NASA/JPL

18. 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
19. 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
20. Other missions in the Soviet Mars series were unsuccessful, including the lander attempt of Mars 7.
21. Horowitz, N.H. 1966. The Search for Extraterrestrial Life. Science 151(3712), 789-792.
22. Dr. Thomas Mutch speaking to BBC News. Available at: http://news.bbc.co.uk/onthisday/hi/dates/stories/july/20/newsid_2515000/2515447.stm
23. The first image transmitted by the Viking 1 Lander from the surface of Mars on July 20, 1976. Credit: NASA Viking Image Archive
24. Post-Viking Biological Investigations of Mars. 1977. Committee on Planetary Biology and Chemical Evolution, Space Science Board, Assembly of Mathematical and Physical Sciences, National Research Council.
25. Viking 1 Camera 1 Mosaic of Chryse Planitia. Credit: NASA Viking Image Archive
26. 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
27. Astrobiology Magazine (www.astrobio.net), “Astrobiology Top 10: Water Flows on Mars.” Available at: http://www.astrobio.net/index.php?option=com_retrospection&task=detail&id=2200
28. 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
29. 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 and 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. Credit: NASA/JPL-Caltech/ASU
30. 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. Credit: NASA/JPL-Caltech/ASU
31. This three-frame image shows a region in the southern highlands of Mars where Mars Odyssey found evidence of chloride salt deposits. These depos-

its could point to places where water was once abundant, then evaporated, leaving the minerals behind. These images of the region were actually taken on March 30, 2007, by the High Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter. Credit: NASA/JPL-Caltech/ University of Arizona/Arizona State University/University of Hawaii

32. European Space Agency. "Europe reclaims a stake in Mars exploration." Available at: http://www.esa.int/SPECIALS/Mars_Express/SEMKR55V9ED_0.html
33. Matsos, Helen. 2004. "Interview with Beagle 2 Scientist Colin Pilinger." Available at: http://www.astrobio.net/interview/interview-with-beagle-2-scientist
34. Astrobiology Magazine [www.astrobio.net]. "Sounding Out Mars: an interview with Jeffrey Plaut." Available at: http://www.astrobio.net/interview/1464/sounding-out-mars
35. 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)
36. Beagle 2 Landing site in *Isidis Planitia*. MOC2-835a: Beagle 2 December 25, 2003, landing ellipse. Credit: Mars Global Surveyor Mars Orbital Camera Image.
37. This photo, taken by NASA's Opportunity rover, shows Mars' thin, diffuse clouds. Credit: NASA/JPL-Caltech
38. Mars Reconnaissance Orbiter Mission Pages: Science Goals. Available at: http://www.nasa.gov/mission_pages/MRO/mission/science-goals.html
39. Astrobiology Magazine. 2006. "Astrobiology Top 10: MGS Bows Out." Avail- able at: http://www.astrobio.net/index.php?option=com_retrospection&task= detail&id=2191
40. Astrobiology Magazine (www.astrobio.net), "MGS Over and Out." Available at: http://www.astrobio.net/pressrelease/2152/mgs-over-and-out
41. Details in a fan-shaped deposit discovered by NASA's Mars Global Surveyor. Credit: NASA/JPL/Malin Space Science Systems
42. 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
43. University of Arizona. Phoenix Mars Mission. Available at: http://phoenix.lpl.arizona.edu/mission.php
44. 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
45. 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
46. Astrobiology Magazine. 2009. "Astrobiology Top 10: Too Salty to Freeze." Available at: http://www.astrobio.net/topic/solar-system/mars/astrobiology-top-10-too-salty-to-freeze
47. 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 May 25, 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

48. 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
49. Astrobiology Magazine. 2010. “Astrobiology Top 10: Viking Results Revisited.” Available at: http://www.astrobio.net/topic/solar-system/mars/astrobiology-top-10-viking-results-revisited
50. Astrobiology Magazine. 2010. “Phoenix Crushed by Frost.” Available at: http://www.astrobio.net/topic/solar-system/mars/phoenix-crushed-by-frost
51. NASA JPL. Mars Science Laboratory. Available at: http://marsprogram.jpl.nasa.gov/msl
52. Astrobiology Magazine. 2006. “Managing Mars Missions.” Available at: http://www.astrobio.net/topic/solar-system/mars/managing-mars-missions
53. Meyer, Michael. 2009. “The MSL Science Story.” Special Planetary Science Subcommittee Meeting, Mars Exploration Program Analysis Group, January 9, 2009, at NASA HQ.
54. NASA. 2009. NASA Selects Student’s Entry as New Mars Rover Name. NASA Jet Propulsion Laboratory. Available at: http://mars.jpl.nasa.gov/msl/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=99
55. Ma, Clara. 2009. “Curiosity.” Essay written by Clara Ma, winner of the Mars Science Laboratory naming contest. Twelve-year-old Ma submitted the winning entry, “Curiosity.” NASA Jet Propulsion Laboratory. Available at: http://www.nasa.gov/mission_pages/msl/essay-20090527.html
56. Schmid, D. Southwest Research Institute. 2012. Radiation En Route to Mars. Astrobiology Magazine. Available at: http://www.astrobio.net/topic/exploration/moon-to-mars/radiation-en-route-to-mars
57. NASA. 2012. Daybreak at Gale Crater. NASA Multimedia Gallery. This computer-generated view depicts part of Mars at the boundary between darkness and daylight, with an area including Gale Crater beginning to catch morning light. Northward is to the left. Gale is the crater with a mound inside it near the center of the image. Credit: NASA/JPL-Caltech. Available at: http://www.nasa.gov/mission_pages/msl/multimedia/gallery/pia14293.html
58. NASA. 2012. Destination for Mars Rover Curiosity. NASA Multimedia Gallery. This image shows the target landing area for Curiosity, the rover of NASA’s Mars Science Laboratory mission. The target is near the foot of a mountain inside Gale Crater. Techniques for improved landing precision give Curiosity about a 99 percent probability of landing within the ellipse outlined in black in this image. The ellipse is 12.4 miles (20 kilometers) by 15.5 miles (25 kilometers). The blue line shows one possible route the rover could take onto the lower flank of the mountain. Credit: NASA/JPL-Caltech/ESA/DLR/FU Berlin/MSSS. Available at: http://www.nasa.gov/mission_pages/msl/multimedia/pia15293.html
59. NASA JPL (2013) Pebbly Rocks Testify to Old Streambed on Mars. Available at: http://www.nasa.gov/mission_pages/msl/news/msl20130530f.html#.U0wiEcfc3Cn
60. Kerr, R.A. 2014. “New Results Send Mars Rover on a Quest for Ancient Life.” ScienceNow. AAAs. Available at: http://news.sciencemag.org chemistry/2013/12/new-results-send-mars-rover-quest-ancient-life
61. NASA. “MAVEN: Answers About Mars Climate History.” Available at: http://www.nasa.gov/mission_pages/maven/overview/index.html

NP-2015-04-1737-HQ