



BY KIMM FESENMAIER

M i s s i o n

t o M a r s

Close to midnight on Black Friday, 2011, John Grotzinger was standing in the swampy darkness at Cape Canaveral, snapping photos of an Atlas V rocket, when a car pulled up behind him. “Oh boy,” he thought. “This is it . . . I’m getting arrested.”

It wouldn’t have been your typical arrest: Grotzinger leads the team of scientists that had prepared the precious payload atop that rocket—the [Mars Science Laboratory \(MSL\)](#), the most capable robotic mission ever sent to the Red Planet. Earlier that November day, a colleague had mentioned to Grotzinger that his badge should allow him to get a close-up look at the Atlas V.

And so, after a series of uncertain turns and a bit of off-roading on the beach, Grotzinger found himself in the dark, just outside the fenced-off launch pad, taking in the beauty of

the illuminated rocket and steeling himself to be hauled off to jail. He wasn’t. The man who drove up behind him that night turned out to be one of the engineers from the Jet Propulsion Laboratory (JPL) who had been at Cape Canaveral doing final checkouts of MSL’s car-sized Mars rover, Curiosity. In fact, with his escort and photography privileges, the engineer was able to take Grotzinger right up to the base of the rocket.

Grotzinger was awestruck. “You get up close and see this enormous thing that you know is going to leave Earth,” he says, “and you know all

these people have worked on what’s inside it, and that this rocket is going to deliver their dreams to the surface of another planet . . . To see it up this close in the dark of night is a reminder of the miracle of engineering, and that we should never take this for granted.”

When the rocket blasted off the next morning—sending MSL on its 352-million-mile trip to Mars—Grotzinger was cheering with the science team in the bleachers at the Banana Creek viewing area. The launch marked the end of the first phase of the mission for Grotzinger, nine principal investigators, and their team of about 300 scientists from around the world. That team had worked with engineers to design, build, test, and integrate the suite of 10 scientific instruments that make Curiosity a fully automated, roving geological laboratory capable of collecting and analyzing samples on the surface of Mars. Now the clock is ticking down as they prep for the next phase, when they will begin receiving images and measurements from Curiosity and using that data to seek evidence of a Martian environment

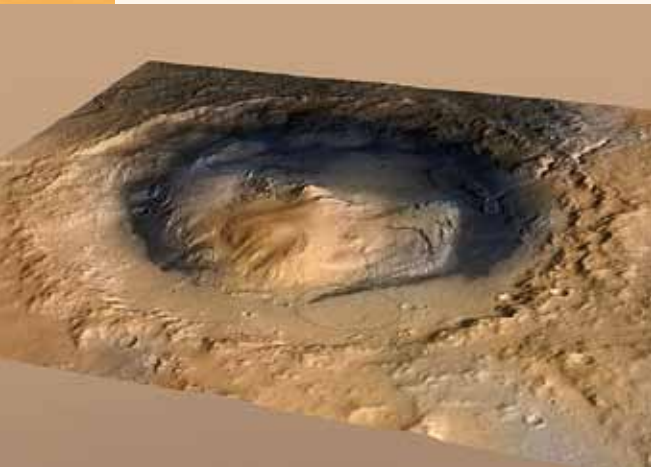
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Due to Curiosity’s size and mass, a new sky-crane touchdown system will lower the rover to the Martian surface. Once Curiosity touches down, the bridle will be cut and the descent stage will fly away.



that could have once supported microbial life.

That phase will begin on August 5 of this year when—if all goes well—MSL will blaze through the Martian atmosphere, traveling at a speed



of some 13,200 miles per hour. In less time than it takes to boil a pot of water—a nail-biting period known as the “six minutes of terror”—the spacecraft will go through a series of maneuvers to put on the brakes and touch down. This will be no small feat: at nearly 2,000 pounds, Curiosity weighs more than five times as much as the previously launched Mars Exploration Rovers (MERs) Spirit and Opportunity, so an air-bag

**Above:** Curiosity's landing plan puts it within Gale Crater, an impact feature on Mars that's more than 3 billion years old. The layered mountain at its center, dubbed Mount Sharp by the science team, is a major scientific focus for the mission.

**Right:** These are replicas of the wheels on Sojourner (center), the first rover on Mars; the Mars Exploration Rovers (left); and Curiosity (right). Curiosity's wheels are approximately 20 inches (50 centimeters) in diameter while Sojourner's were closer to 5 inches (13 centimeters).

bounce landing like theirs is out of the question. This time around, stages will jettison, an enormous parachute resplendent in orange and white (in Caltech's honor) will unfurl, and eight retrorockets will fire. Then, in a dramatic final act, MSL's descent stage, positioned above the rover, will behave like a sky crane, lowering Curiosity on long tethers to the surface of the planet.

#### WELCOME TO GALE CRATER

That action-packed entrance should leave the rover poised on all six wheels inside Gale Crater, an ancient impact crater just south of the Martian equator. Roughly the size of the Los Angeles Basin—at 154 kilometers (96 miles) in diameter—the crater is the kind of place geologists would head to on Earth to search for evidence of past life. They hope to find organic compounds, the carbon-containing chemicals considered necessary for life. So finding the crater on Mars, at a safe elevation with moderate environmental conditions, made it a natural choice for the mission.

The floor of Gale Crater is at a low elevation relative to its surroundings, which means that if water once flowed across Mars, Gale might have been a location in which groundwater collected and perhaps even emerged as an ancient lake. But the main attraction at Gale is a mountain that rises five kilometers (three miles) from the crater floor. The science team has dubbed this geological feature Mount Sharp in honor of the late Robert P. Sharp (BS '34, MS '35), the beloved former chair of Caltech's then Division of Geological Sciences, who built the Institute's program in planetary sciences. Scientists hope to use Curiosity and its scientific instruments to read the history of Mars by characterizing Mount Sharp's strata—beginning with its oldest layers at the bottom and inching up to those deposited more recently. Previous orbital missions have already identi-

fied the chemical signatures of clays and sulfate minerals, which are formed through interaction with water, in the lower parts of the mountain. On Earth, these minerals are often found with—and help protect—organic compounds. All this makes the mountain a promising place to begin investigating the planet's past habitability.

“We don't know what the story is going to be at Gale Crater, but we've got a wonderfully simple exploration model,” Grotzinger says, “We'll just start at the bottom of the mountain, interrogate the layers and make the measurements, and see what the planet's trying to tell us. I don't think we can lose.”

Ideal though the location may be, it took the scientific community about five years to settle on Gale Crater as MSL's landing site. “The amazing thing is that, thanks to MSL's landing system, we scientists got to consider—for the first time ever—the absolute best places on Mars,” says Grotzinger. “The whole time we were debating, I had seasoned veterans telling me, ‘John, don't get your hopes up, because in the end engineering constraints will probably kill all of these choices. Be prepared to accept whatever's left on the table.’ But we didn't have to settle. In the end, we chose the site that was actually the science team's favorite, and the engineers could support it.”

#### SAM I AM

Curiosity is uniquely equipped to select, sample, and analyze rock and soil



targets once it arrives on Mars. Indeed, JPL deputy project scientist Ashwin Vasavada (PhD '98) describes the rover as "a Mars scientist's dream machine." Its onboard tool kit includes not only devices that are the equivalent of the hand lens and drill geologists rely upon in the field, but also the spectrometers and other analytical instruments they might use in the lab to identify the chemical elements, minerals, and gases in their samples. The rover sports several cameras that will allow it to observe its surroundings in high definition and

Once Curiosity drills into a rock or scoops some soil to harvest a sample, its six-foot robotic arm will go through a series of tai-chi-like maneuvers to process and deliver the materials to the rover's belly, where they can be analyzed by two advanced onboard laboratories. One, called CheMin, will use X-ray diffraction to identify minerals in the sample. The other, called SAM (for Sample Analysis at Mars), is a suite of three analytical instruments—two spectrometers and a gas chromatograph—that can check for large organic molecules and other important chemical elements, measure isotope ratios to look for signs of past planetary changes, and determine concentrations of gases in both surface samples and the Martian atmosphere.

"Such information will be invaluable in reconstructing the geological and environmental history of Mars which, in my view, is the key to addressing the capacity of past and present Martian environments to support life as we know it," says Edward Stolper, Caltech's provost and William E. Leonhard Professor of Geology. He served as MSL's chief scientist from 2005 to 2007 and helped coordinate early development of the rover's scientific capabilities.

Although Curiosity is equipped to identify organics (and finding them would certainly be a grand slam for the mission) the likelihood of such a find is extremely low. That's because the surface environment at Mars is thought to be chock-full of chemicals that degrade organic matter. Compounds such as hydrogen peroxide and perchlorate, which can convert organics into carbon dioxide and other chemicals, have been detected in the Martian soil and atmosphere. Ultraviolet solar radiation and high-energy radiation from incoming cosmic rays can produce highly reactive radicals that readily alter organic matter, rendering it undetectable. Even water, which enables life to exist, tends to

wipe away traces of organics because it is also an oxidant. So even if life *had* once thrived on Mars, scientists would be hard pressed to find traces of it. In fact, on Earth—a planet that teems with life—the record of life in the form of organic matter is rarely preserved over geologic time.

Not to fear, though: MSL's success does not hinge on finding organic matter. Simply by driving up the mound in Gale Crater, taking samples, and reading the layered record it encounters, Curiosity will improve our understanding of the evolution of Mars. And if it can reach a spot about a quarter of a mile (about 400 meters) up Mount Sharp, it should find a break point that may mark a geologic transition between the period when Mars was able to form hydrated materials and when the planet began to dry out. "The deterioration of Mars's early, more clement climate to the inhospitable conditions that characterize the planet today is one of the great mysteries of planetary science," says Grotzinger.

#### MEANWHILE, BACK ON EARTH

While Curiosity wends its way to Mars, Grotzinger and his team of scientists are doing more than just twiddling their thumbs. At JPL, rover drivers are practicing their Martian navigation using Curiosity's earthbound doppelgänger, remotely controlling the movements of the rover and its arm in either a warehouse test bed or an outdoor "Mars Yard." And the rest of the science team is working out final details related to the rover's instruments.

One working group, for instance, is compiling a list of all the different situations that could be serious uh-ohs for Curiosity's sample-handling system—such as materials that give off fluid, become sticky upon heating, or are extremely hard. "Realizing we're going to see minerals on Mars that we've never seen before, and that we



in three dimensions. Its laser eye, called ChemCam, will zap rocks and other targets of interest from as far away as seven meters (23 feet), enabling an onboard spectrometer to get a sense of the target's composition. And Curiosity will have the ability to measure radiation, screen for water in the ground, and monitor the Martian weather.

An early parachute design undergoes testing in the NASA Ames Research Center's wind tunnel. Although the final parachute design is slightly different, it retains Caltech's colors.

will have no way to really know what they are before we sample them, we have to do some hazard assessment before we would ever risk drilling into them," says Vasavada. That's why the group is testing terrestrial samples with some of these potentially problematic characteristics, and doing so in a chamber that replicates the humidity and temperature at Mars, all to see how the sample-handling system responds.

The most recent group of researchers to join MSL's science team is also busy prepping. These "participating scientists" were selected last November based on what they proposed to contribute to the mission. Caltech geologist Bethany Ehlmann wants to improve the science team's ability to respond to the data Curiosity sends back about potential rock targets. Plastic tubs in her office at Caltech are filled with basaltic rocks that have been altered in different ways through interaction with water—the same types of alteration that rocks on Mars might show if they have come into contact with water for various amounts of time. She plans to fully characterize as many of these rocks as possible, even taking them to Los Alamos National Laboratory, where she and her students can zap them with a laser similar to the ChemCam laser on Curiosity. This should help the team recognize which rock targets on Mars are worth taking a closer look at, and which to leave behind.

This isn't Ehlmann's first time at this kind of Martian rodeo. She helped operate the rovers Spirit

and Opportunity—which landed on the planet within a few weeks of each other in January 2004—as an undergrad. She and the rest of the MER team even lived on "Mars time" for a few months, which essentially meant starting each workday 40 minutes later than the one before. (Martian days, or sols, last 24 hours and 40 minutes.) Curiosity's team also plans to live on Mars time for at least a few months, arriving each day just before the downlink of data from the rover's previous sol and working through the Martian night to come up with and upload fresh commands for Curiosity to execute the next Martian morning.

One of the hardest aspects of living on Mars time, Ehlmann says, is eating. "If your 12- or 13-hour shift plus your sleep time misalign with when the grocery stores or restaurants are open, you can start to wonder, 'How do I get food?'" she says. When JPL thanked the MER team for its hard work by filling coolers outside the workrooms with ice-cream treats, the running joke became, "How many ice creams have you eaten today?" Ehlmann laughs. "There were a lot of three-ice-cream days. Those

couple of weeks of subsisting off ice cream were a good camaraderie-building experience for us."

That sense of camaraderie comes up time and again when people describe working on missions like MSL. Part of that closeness is based on the fact that everyone is pretty much in the same situation—waiting for new data, trying to make sense of it once it arrives, and working to make the best decisions for the rover. There's also an understanding that every member brings a different base of knowledge and experience to the team and that each skill set will be vital to the mission at different times.

Geochemist Kenneth Farley, for instance, brings a wealth of expertise in measuring noble gases in rocks. He was selected to be a participating scientist based on his proposal for determining the age of some of the geologic features Curiosity will encounter. He plans to use the rover's SAM suite of tools to measure concentrations of a helium isotope, helium-3, in heated samples. Helium-3 is the result of the extremely energetic nuclear particles that are always bombarding the surface of Mars in the form of cosmic



Below: Curiosity is the most scientifically capable rover ever sent to another planet. A rotating turret at the end of its robotic arm includes tools for studying rocks up close, as well as a brush, scoop, and drill for collecting fine samples of rocks and soils for study by the rover's analytical instruments.

rays; when they hit rocks, they shatter atomic nuclei and form isotopes such as helium-3. "If you know the rate at which these catastrophic interactions occur and you measure the isotopes that come out, then you can determine how long something has been exposed on the surface," Farley says. This could help the team select sample rocks that have been exposed for shorter periods and should thus be less altered than those that have been on the surface longer.

Since Mars geology isn't his main research area, Farley thought his proposal might be a long shot. "But," he says, "it just seemed like something that could be tried."

Back in 2001, John Grotzinger might have said something very similar. An expert in the analysis of sedimentary rock, Grotzinger has spent the majority of his career studying geology all over the world—from Northern Canada to Siberia, from Western Australia to Namibia and Zimbabwe.

But while Grotzinger was unearthing rocks in Oman, trying to better understand the composition of the biosphere 500 million years ago, a colleague suggested he submit a proposal to become a participating scientist on the MER mission. All the pictures Grotzinger had seen of Mars featured basaltic—rather than sedimentary—rock, but he decided to give it a shot. "If nothing else," he says, "I figured it would be a fun experience, and if I didn't have much to add in the end, I could go back to what I was doing."

As it turned out, shortly after Opportunity landed, the rover started relaying images of layered rock outcrops, and Grotzinger's expertise became absolutely essential; now, at the helm of the 300-plus-member science team, he'll tell you he's never really looked back.

But, if you push a little, he'll admit that maybe, just maybe, he enjoyed that evening visit to Cape Canaveral and the Atlas V rocket so much because it felt something

like being back in the field. He'll admit that maybe, just maybe, he misses fieldwork. But then he'll remind you that he's even more eager to see what his team's robotic emissary will find in the Martian fields.

"Even if we don't ever find life on Mars, if we understand the evolution of its environment, we might understand why life *didn't* evolve on Mars or why it took the particular pathways it did on Earth. And that," he says, "would be remarkable. It's what science is all about." **ESS**

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**John Grotzinger**, chief scientist for the Mars Science Laboratory, is the Fletcher Jones Professor of Geology at Caltech.

**Ashwin Vasavada (PhD '98)** is one of two deputy project scientists for MSL. He is a research scientist at JPL.

**Bethany Ehlmann** is an assistant professor of planetary science at Caltech and a research scientist at JPL.

**Kenneth Farley** is chair of the Division of Geological and Planetary Sciences and the W. M. Keck Foundation Professor of Geochemistry at Caltech.

JPL built MSL's rover and descent stage and manages the mission for NASA's Science Mission Directorate in Washington. More information about Curiosity is online at <http://www.nasa.gov/msl> and <http://mars.jpl.nasa.gov/msl/>. You can follow the mission on Facebook and Twitter at <http://www.twitter.com/marscuriosity>.

