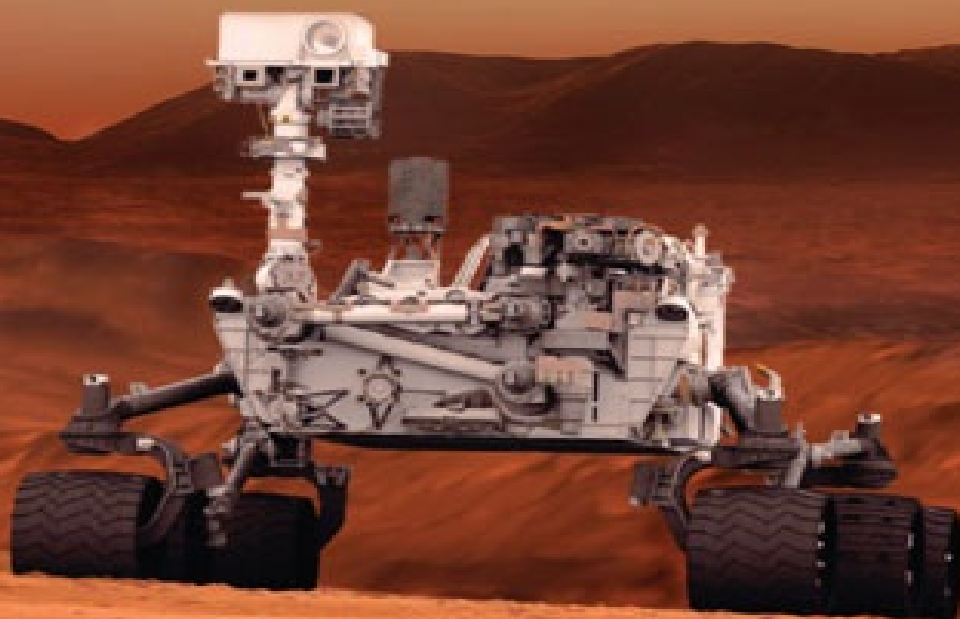


ROD PYLE

CURIOSITY



An Inside Look at the MARS ROVER MISSION
and the PEOPLE WHO MADE IT HAPPEN

ALSO BY ROD PYLE

Destination Mars: New Explorations of the Red Planet

CURIOSITY

An Inside Look at the MARS ROVER MISSION
and the PEOPLE WHO MADE IT HAPPEN

R O D P Y L E

 **Prometheus Books**
59 John Glenn Drive
Amherst, New York 14228

Published 2014 by Prometheus Books

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Cover design by Nicole Sommer-Lecht

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WWW.PROMETHEUSBOOKS.COM

18 17 16 15 14 5 4 3 2 1

The Library of Congress has cataloged the printed edition as follows:

Pyle, Rod, author.

Curiosity : an inside look at the Mars rover mission and the people who made it happen / by Rod Pyle.

pages cm

Includes bibliographical references and index.

ISBN 978-1-61614-933-8 (paperback) — ISBN 978-1-61614-934-5 (ebook)

1. Roving vehicles (Astronautics) 2. Curiosity (Spacecraft) 3. Mars (Planet)—Exploration. 4. United States. National Aeronautics and Space Administration. I. Title.

TL799.M3P95 2014

559.9'23—dc23

20140075

Printed in the United States of America

*To my son, Connor:
The future is yours,
use it wisely.*

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ACKNOWLEDGMENTS

Thanks are due to countless people who generously gave of their time and energies to assist in the completion of this book. The bulk of these people work at JPL, either on staff or as contractors, and rarely get the thanks or recognition they deserve.

First and foremost: my deepest thanks to the selfless Guy Webster, as fine a person as you are like to meet during your brief time on our planet. He is the media's point man for JPL's Mars program, and gives and gives without complaint or hesitation, which is rare in his area of endeavor. And—he knows his stuff; Mars is no stranger. I simply cannot thank you enough.

John Grotzinger, who was kind enough to survive my many questions, most of which are well below his pay grade. John made time for me on numerous occasions when I'm sure he had better things to do (like exploring Mars, for example). John, I am in your debt for the many hours you spent educating me on things I did not know I needed to know, and making it fun.

Rob Manning, a fantastic guy, gave me more time than I could have asked for and did so with copious good grace. He is a font of information presented in a way that is as enjoyable as it is informative, and the fact that he enjoys it so much means that all of us do too.

Very special thanks to: Ashwin Vasavada, Dan Limonadi, Joy Crisp, Justin Maki, Mike Malin, Ken Edgett, Scott McLennon, Lauren DeFlores, Vandi Tompkins, Doug Ming, Brian Cooper, Rebecca Williams, Al Chen, Steve Squyres, Chris McKay and Jakob van Zyl. You all provided time for interviews in schedules that were already jammed to the hilt. My thanks.

To Buzz Aldrin, who made time for questions about this story as well as others; you are a founder of the Space Age, and one of the few key players who continuously strives to push open the frontier. Mars owes you much.

Robert Zubrin, whose work underlies so much of manned Mars planning now it's hard to find the borders of his involvement. Thanks for being a selfless champion of the red planet. Alexandra Hall of the Google Lunar XPrize: you will first win the moon, then Mars. Carry on.

Steven Dick, former NASA chief historian and now astrobiology chair for the Library of Congress and Roger Launius of the Smithsonian NASM, thanks as always. Leonard David, space journalist and fellow niche author: thanks for being there.

Steven L. Mitchell of Prometheus Books: your continued support of planetary exploration and the sciences at large are a testament to the integrity and high standards of Prometheus. We are all better for your efforts. And to the rest of the Prometheus Books staff: Catherine Roberts-Abel, Melissa R. Shofner, Bruce Carle, Nicole Sommer-Lecht, Jade Zora Scibilia, Mariel Bard, Meghan Quinn, and those who worked behind the scenes—thank you.

John Willig, ever-present agent and supportive friend, who wrangled the details and made it look easy as he always does. Deepest thanks once again.

Blaine Baggett runs a tight ship at JPL and it shows. The communication division works wonders with limited resources. Veronica McGregor, Jane Platt, Jia-Rui Cook and D. C. Agle make this sort of thing possible.

To the rest of JPL's able PR staff: Elena Mejia, Mark Petrovich, Daniel Goods, Erik Conway, Scott Hulme, and John Beck-Hoffman—thanks for responding to my continuous (and probably irritating) requests for media materials. There is simply no way for an author to approach such a task without

your talents and support.

~~Lawren Markle and Brian Bell of Caltech's media relations: thanks for your accommodation~~
Lawren has since moved on, but may well have saved me from becoming a permanent part of Death Valley.

Janice Alvarez provided tireless transcriptions on time and with remarkably few errors or omissions considering the complexity of the work—and while delivering a new baby, no less. I have no idea how you did it.

Thanks to my pals from the Griffith Observatory days who generously donated their time to JPL during the Curiosity landing: Jim Somers and John Sepikas. You made the landing a whole lot easier for the press; they will never know what you did for them. Glenn Miller helps you stay the course. And Bob Brooks, who is at JPL every day—Mars would not be the same without you.

Thanks to Ken Kramer, Sherry Clark, and Scott Forbes, for being there. To my son, Connor, who endured countless hours of silence and separation (do teenagers even notice?) while I operated in missile-silo mode to write: thanks for being understanding.

Sherry Clark, you are a pillar of strength and support. Gloria Lum, your contribution to this process is too much to write. Thanks.

To mom and dad: thanks for being understanding of a sometimes-puzzling son.

To the readers: thanks for being understanding of a sometimes-puzzling adult. I love writing books and your support is the greatest treasure any author can ask for.

AUTHOR'S NOTE

Any book such as this requires a vast amount of research and cooperation with the National Aeronautics and Space Administration (NASA), the Jet Propulsion Laboratory (JPL), Caltech, and other appendages of the government/academic space-exploration enterprise. Of course, the richest resources are the people within, and the larger NASA entity is filled with wonderful and helpful ones who have vast experience and long memories. In particular, the exploration of Mars is an undertaking that inspires great passion in the participants, fostering deeply moving and fascinating conversations.

I interviewed dozens of participants in the Mars Science Laboratory (MSL) mission for this book, and it draws upon their statements and memories liberally. In all cases they demonstrated an accurate memory of entry, descent, and landing akin to people's memories of where they were when Apollo 11 landed on the moon, or for the younger generation, that awful day when the space shuttle *Columbia* disintegrated during reentry. Other memories and recollections of duties and actions taken since landing, during the primary mission, were also fresh. For the scientists, their summaries of the particular areas of interest were detailed and exact. Likewise for the engineers; their recall of the portions of the mission and the technologies within were acute and complete. These recorded interviews were later transcribed into about three hundred pages of text for reference.

For the recounting of specific statements and events not covered within interviews (or requiring backup), I relied on two primary sources. The first, where applicable, were the vast amounts of archival video footage of various phases of the MSL mission which are available online both through publicly accessible NASA websites and by request via JPL's servers. One may also order footage from JPL's vendor if desired. Thousands of still photos back up this visual data, too. The second source was the statements of other participants in the mission themselves, and in cases where there was an apparent mismatch or doubt, I attempted to find a third source to support individual claims.

In absence of other recorded data, Guy Webster, JPL's point man for Mars, has a vast institutional memory and was helpful when other methods failed. He is a rich resource.

For older missions and histories, NASA has massive archives spread across the web and in various physical locations—specific to planetary exploration, JPL, Caltech, and Nils Bohr Institute archives can be particularly helpful.

All this said, one occasionally finds an error or misquote that has been propagated across time and space—something printed twenty-five or thirty years ago, then erroneously quoted in another book or article, *then* archived among a half dozen or more web portals, can become very thorny to unravel, especially when (as sometimes occurs) the primary reference may have gone missing. Fortunately, MSL is a young-enough mission that this is not yet a concern. In fact, part of NASA/JPL-Caltech's challenge with this mission is to preserve and archive events and documents as they happen, with very little budget to do so.

The vast bulk of the imagery in the book comes courtesy of NASA/JPL-Caltech. Their online image archives are superlative, and in most cases the accompanying captions make clear the phase of the mission related to the photo at hand. A few other images were sourced from stock agencies or Creative Commons sources. Still others come from my personal collection.

Review and some fact-checking was performed by JPL and in some cases specific mission participants. Any remaining mistakes are my own.

CHAPTER 1

DEATH VALLEY DAYS

Vultures cut lazy circles in the sky above me, patiently awaiting my certain demise. Dropping my gaze, I could see the heat shimmering off the mountainside. It was well over one hundred degrees and the last of the water was long gone. I was close to forty miles from the nearest road and the situation looked bleaker than the late dinner seating on the *Titanic*.

What did this potentially life-threatening situation have to do with Curiosity on Mars?

Then the image of Lawren Markle, the dapper (and sweatless, in stark contrast to my drenched shirt) PR rep from Caltech, swam into focus before my parched and crispy eyes.

“You doing OK?” he said with a look of genuine and entirely reasonable concern, given my condition. “Sure,” I croaked. “I’m...good...” It was then that the death fantasy evaporated and I was back in an equally grim state—atop a barren, rocky peak in Death Valley with a group of scientists, journalists and our Edmund Hillary–esque geological guide, Caltech’s Dr. John Grotzinger.

I looked from Grotzinger, who was holding forth on a geological premise that was not quite soaking in, to Lawren, who had refocused his attention to Grotzinger, where it belonged. Having Grotzinger as our tour guide in this garden spot of Death Valley was a true privilege. If I survived it, I would be very grateful in a week or so, once I was able to rehydrate.

Reality hit: we were probably a mile from the road, it was about eighty-four degrees, and we had been hiking for about twenty minutes. I was wiped out. This was not promising to be my best day.

The invitation I received in my e-mail a week before had sounded exciting and bore the return address of Caltech. I was invited to join Dr. John Grotzinger, mission scientist (a.k.a. Big Kahuna) from the Mars Science Laboratory, as he hosted a two-day press junket into Death Valley to discuss some of the formations that informed earthbound geologists about what they might find on parts of Mars. It all looked like good fun, and there would be only a handful of us, maybe twelve science writers. I would be the sole outside video guy; JPL’s John Beck-Hoffman would shoot for their media operation.

At the end of the note was added, “Wear sturdy shoes, as we will do a bit of walking.” Oddly, I missed the hidden meaning even though I had taken a string of geology classes in college. I should have remembered that this was geologist’s code for “wear steel-toed boots, as we are likely to run into rattlers and possibly even desert snarks as we hike over hill and dale looking for the perfect Precambrian outcrop”...or in this case, as we hike about twelve miles, mostly vertical, in the hottest and driest place in the continental United States.

What may have thrown me off was that Grotzinger is not the old-breed of geologist I knew from my increasingly distant college days. He wore no suspenders, no plaid flannel shirt, and did not smoke a pipe. He had no gold-miner’s belly hanging over a turquoise-buckled beltline. He is, in fact, tall, slim, irritatingly fit, and tan. His weathered good looks would be welcomed into the Explorer’s Club. While his explanations can be challenging to follow, he is patient and graceful with the laypeople. He can be folksy and technical in the same sentence, so clearly the geologist’s pedigree was there.

We traversed many roads and junctions on our way into the high desert, and the map showed many nearby avenues with such charming (and informative) names like Talc Road, Sulfate Road, and Cactus Flats Road. A few hours out of LA, we reached our destination: Shoshone, California, with

population of thirty-one. Our group almost doubled it.

As we checked in at the cinder-block penitentiary that was to serve as our motel for the night, a optimistically named “inn,” Grotzinger wandered over to one of the hulking, chalk-white Caltech SUVs that had transported us there. By the time I got my camera equipment and other packing stowed in the room, he was completing elaborate dry-marker murals on the rear passenger-side door of one of these overwrought grocery haulers. Big murals. Murals of complicated rock bedding, uplift, and other geological delights. And on the front door, he had drawn surprisingly artistic renderings of very steep Alpine-looking mountains, which I hoped were metaphorical. As I watched, and thought back to my own college geology field trips, I wondered if any of his compatriots had ever swapped out a permanent marker in the SUV drawing kit just for laughs. I know I would have. “Ha ha, that was funny. Here's the turpentine...oh, that takes off the car's paint too, now doesn't it...”

As we waited for the formal talk to begin, a three-foot-long and very red snake worked its way across the roadway and for some reason (probably seeking the same relieving shade that I would soon pine for) decided to work its way through the spokes of the truck's wheel. Our group tittered nervously. Most of us were now regretting the light athletic shoes we had chosen to wear.

We moved to a fire ring nearby (why a fire ring in Death Valley, you might ask? To keep the sidewinders and rabid coyotes away at night, of course), and Grotzinger began discussing the day ahead. I missed most of it because I don't shoot video out on location all that often and was fiddling with my camera gear and cleaning the sand off the parts I had already dropped twice. But I had been running by the time he got to the most immediately relevant part of the talk, moving back to the mural on the Suburban. “Then we'll end up at this formation, here in the foothills. It's the Glimmenshohn Finkleheimer formation of pregladular hermphratite...”(this was not exactly what was said, but it's how it registered in my overheated brain).

I was still rolling video, so I meekly asked, “John, for *my* audience would you mind giving me the eighth-grade, *Weekly Reader* version of the story?” He paused for a moment, looking at the ground. I thought perhaps I had committed some kind of faux pas, but I think he was merely gathering his thoughts. At least I hope so.

“Um, OK. So what these structures represent is a feature called stromatolites, that we interpret on Earth to represent the interplay between microbial mats that are living on the seafloor and sediment that comes in and interacts with the mat. The sediment is ultimately why it becomes a rock. If it's just left as a microbial mat, the organics will decay and there will be no record of that, but by having the sediment come in, it can get cemented and turn into a rock. Then we see these features in the rock record and infer that there were once microbes living on the seafloor that were forming these structures.”

He paused for a moment to make sure I was getting it. At least the camera was. He continued, “What it has to do with the MSL [Mars Science Laboratory] mission is that it represents an essential member of a feature that, if we saw it on Mars, we would stop and definitely study the outcrop. Immediately there would be a lot of discussion, because even on Earth we cannot take this rock and bring it back to the lab and prove to you unequivocally that this feature represents evidence of life on the early Earth.” As we will learn later, and I promise it will be simpler, on Earth these stromatolite-like features *can* be caused by living things, or they can be mimicked by processes having nothing to do with life. On Mars it would be (a) a wonderful shock and (b) a guaranteed conundrum. “[On Earth] if you put in the context of other features that occur along with it, it's a perfectly reasonable suggestion that these were microbial mats on a seafloor. But independent of that, in rocks of this age, we often see microfossils. I would say that if we ever found something like this with MSL, we would stop and study it, and it might be a really good place to come back to someday in the future and do a sample return to Earth.” Not to mention a press sensation and a tenfold increase in planetary-exploration

budgets. But I digress.

He stopped, flashed what felt like a sympathetic smile, and it was time to move on with the adult portion of our program. I envied the grad-student assistants present that they could understand the version that was to come.

Soon we headed out to the first stop on the side of the scenic Western Talc Mine Road. Once disembarked, Grotzinger began with a sweeping gesture toward some distant hills. “See those white areas over there? They are due to this rock,” He gestured to a chart he had prepared, “which is showing to have a cross-cutting relationship where it comes up and goes into the Crystal Springs formation there...” Pointing to a specific spot (that looked to this layman like more gray hillside), “It's a basaltic composition rock, and that's a Mars kind of rock. It's not a granite; it's got olivine and pyroxene in it or once had it, and it intruded into the Crystal Spring adjacent to some carbonate rocks...and it heated and altered the rock. You'll hear that from the Mars guys, especially the mineralogists, talking about alteration. Well, that white rock is a result of alteration, it's a mineral called talc.”

I felt a moment of pride, for I knew what talc was. It comes as a powder in bottles and lives in bathrooms.

“We're going to go right up there to see the talc and the carbonates that it's intruding into, so you will see the source of the heat which is the basaltic rock. It intruded in, and then it heated up the sediments which were wet, and it made talc, which is a hydrated magnesium silicate mineral, kind of like a clay.”

Aha! Understanding crept into my brain. If Curiosity found clays on Mars, that would be evidence of water, and there were many complex processes under which this alteration into clays might take place. This one had involved intense heating.

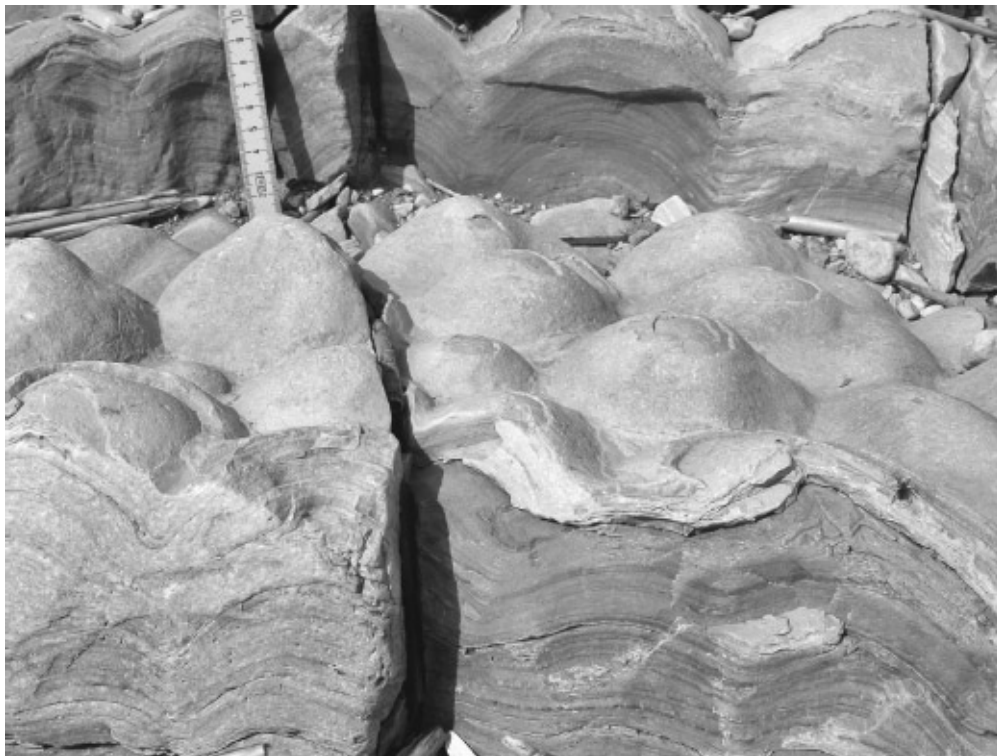


Fig. 1.1. STROMATOLITES: This is one form (of many) that stromatolites can take. They can be caused by either biological or nonliving activities, and it can be difficult to discern one from the other. Still, were something like this found on Mars, it would grab the attention of the geologists. *Image from Mark A. Wilson (Wilson44691).*

Overall, this was a dense subject, somewhat above my pay grade, but clearly Grotzinger loved the topic and while it may have been a challenge to talk at our level, his enthusiasm was highly infectious.

We loaded up the trucks and headed out to some barren, rocky mountains in the lowest, hottest

place of America.

~~Less than an hour later, we were in the foothills heading to the first hike of the day.~~ Leading up to this, the sights had been within a few dozen yards of the highway. This had suited me fine, what with my twelve-pound camera and eighteen-pound aluminum tripod (the lighter, carbon-fiber ones are expensive...I pride myself on equipment frugality and never understood those guys who spend thousands on carbon-fiber tripods—I soon would). It was early and I had already sweated out a few quarts into my designer tropical shirt, vented at the back as a fashion statement.

As we unpacked for the hike, I took stock of my companions. There were about a dozen of us, including Mike Wall, my compatriot from Space.com. He was writing a story and I was shooting on video. I would soon admire his choice of a pen as an instrument of communication over my camera. Others were from the *Wall Street Journal*, *Reuters*, *New York Times*, *Washington Post*, *New Scientist*, and the *LA Times*. And then there was Beck-Hoffman, the JPL camera guy who was annoyingly fit and nimble (and who would soon be known as the *auteur* behind the “7 Minutes of Terror” video that was downloaded millions of times). He was carrying a large, shoulder-mounted camcorder. It would slow him down far less than my smaller rig would me.

We parked on a mesa and headed off, following Grotzinger toward a series of hills. They didn't look like much from the starting point. But by the time we got to the bottom of them, they were impressive indeed. Funny how these things magnify in intimidation when you get closer—the desert compresses everything from a distance. The group made its way up, each at his or her own pace but in little clouds of people—and then there was me. To be fair, I was carrying the camera in one hand and the tripod over the opposite shoulder, trying to balance myself as we climbed the rough, bouldery hillside. At least that's the excuse I was using. Within moments, I was out of breath, panting like a dying asthmatic, and falling behind. I looked from side to side—there were mounds here, surely shallow graves of journalists who had gone before me. But I stuck with the program.

When I reached the top, the lecture had begun and the other journalists were taking copious notes. I set up my camera with slippery, sweaty hands, and once the ringing in my ears abated, which for a moment I thought might be the signs of a mild stroke, I listened to Grotzinger speak on the formation of the desert at hand.

No sooner had I caught my breath than we were on our way farther up the hill. To the top. Which looked very far away. I shouldered the camera rig and followed at an ever-increasing distance, Lawrence shooting worried (and deservedly so) glances my way from time to time. It's nice to be cared about when you're in extremis. On the other hand, I guess it would have been bad publicity for Caltech to host the death of overweight, out-of-shape, late-middle-aged journalist.

For the rest of the day we climbed, descended, and climbed again. The rocks were sharp and nasty. Grotzinger literally scampered hither and yon and most of the journalists were keeping pace, albeit with an increasing gap between themselves and Grotzinger. And then there was the gap between them and me. Leave me, save yourselves.



Fig. 1.2. WHY THEY CALL IT DEATH VALLEY: This was not the region we visited, but it's close enough to give you an idea of how the place got its name. Fascinating, lovely...and on the wrong day, deadly. Summer temperatures can top 130°F. *Image from iofoto.*

We came to another mountaintop (OK, it was a hilltop but give me some dignity), and Grotzing waited for the group to settle. I approached as he began his talk. He was not even sweating. “If you look carefully enough, you will see that these things all go in the same direction. So if you walk up a bit you'll see more of them, then we'll go around the corner where you can see a really big one, about 1 meter in diameter. Have a look, then we can talk some more about it.” He walked off to chat with another husky, bearded fellow (he could pass as a younger version of me, without the cardiac issues) Ken Edgett. Ken is a geologist who works for Malin Space Science Systems (MSSS), makers of the main imaging cameras on Curiosity (and imaging systems of other spacecraft that have orbited Mars). He wasn't sweating either.

The landscape was pretty in a bleak way, but I had missed the actual subject of the stop. I resolved to be more prompt to the next one, even if it meant an early demise.

The remainder of that day and the next followed in a similar pattern, and a night of deep sleep did a little to lessen the impact of the second day's calisthenics. It was informative but challenging. At the end of the second afternoon, I pigeonholed Mike Wall and asked him to summarize the trip. He has a doctorate after all (though in an unrelated field) and is the senior writer for Space.com.

He summarized the excursion succinctly: “John walked us through what field geologists do, how you can make sense of all the different rock layers, what they mean, how they were deposited, and so forth. It was a great exercise. Couched in this is what Curiosity will be doing on Mars and how we can try to make sense of the sort of rocks and formations that we may find in Gale Crater.”

He thought for a moment and continued: “It's a process, it's all context and getting to know the environment. We learned that it's harder than you think it is, that you really need to know the rock

It's going to be hard for a robot to do that on a different planet, but MSL has a great support team, over four hundred scientists who are working on the project. They will interpret all this incredible data that the rover will gather. They are very smart people and will figure it out."

Looking at my sweat-soaked shirt, he smirked and added, "It's windy, but not even one hundred yet, maybe ninety-five degrees. Easy."

I thanked him and returned to the air-conditioned Suburban. We headed back to civilization to witness the beginning of the most ambitious and incredible mission to the surface of another world ever attempted.

CHAPTER 2

TANGO DELTA: TOUCHDOWN

As you have probably surmised, John Grotzinger is not normally a nervous man. A career geologist and professor at the California Institute of Technology (Caltech), he seems equally at home running a huge spaceflight project as he is in front of a class of anxious undergraduates. He jokes easily, and his explanations can be disarmingly folksy but can also turn deadly serious when explaining the relevance of contact metamorphism in a rock. Both are useful traits in his area of endeavor.

But tonight is different. Tonight the stakes are high indeed. Tonight, \$2.5 billion of Mars rover, the aptly named Curiosity, will either land in Gale Crater to begin its twenty-four-month (one Martian year) primary mission, or pinwheel into costly wreckage across a couple hundred acres of Martian desert. Tonight will be either a validation of a decade of planning, designing, building, and launching of a wonderful era of exploration, or the likely end of America's Mars exploration program.

So tonight, Grotzinger seems as nervous as a cat on the freeway.

You would never guess it just by looking, of course; geologists don't roll like that. It can be easier to gauge the feelings of his associates in mission control at the Jet Propulsion Laboratory. Dozens of engineers, controllers, scientists, and other highly proficient people surround him in the final moments of the flying phase of Curiosity's mission, and some display their feelings a bit more directly. Perhaps it is because each of them has been intensely focused on a smaller part of the mission—parachute deployment, entry and guidance, pyrotechnics, software design, or one of a dozen other specialized areas. Grotzinger, as the principal scientist of the mission, must be conversant in each specialization of MSL yet also possess a more global perspective, that is, to oversee the mission once on the ground. Tonight there is not much that he can do except wait and hope.

A few consoles forward sits a man whose face is known to Mars enthusiasts worldwide but whose name may not be. Middle-aged and graying, he is nonetheless clearly still the smiling, ever-cheerful man we saw flashed so memorably across the Internet, fist-pumping the air when Mars Pathfinder landed successfully in 1997. He was thinner and darker-haired then, but the effervescent energy is still there. Rob Manning may have matured, but he is once again the chief engineer in charge of a Mars machine, and there is nowhere he would rather be. It shows.

Rob is not a professor, nor does he hold any official positions outside JPL. He has been the main machine guy for every Mars rover to date—that is his *raison d'être*. He is also father to two precocious daughters and plays jazz trumpet gigs in his scant spare time. Back at work, after sweating out the pioneering Pathfinder mission in 1997 and the design and landings of both Mars Exploration Rovers, Spirit and Opportunity, in 2004, he is at the crescendo of his career with Curiosity. It's been a long haul, though, and the endless hours of meetings and checkouts and visits to the cape have taken their toll. He will rest when the rover is on the ground—in one piece or in hundreds. For now his normally cheerful face shows intense concentration as he follows the data coming back from Mars. So far Curiosity, as much a third child to him as any machine could be, is doing fine.

Down near the front sits a man whose face—or, to be more precise, whose hair—will soon be iconic. Bobak Ferdowsi sports a wild, multicolored Mohawk hairstyle, a personal statement of celebration for this momentous mission. It's like nothing we have ever seen in mission control, and

within hours the Internet is alive with tweets and posts about this new phenomenon. Bobak, in his late thirties, is a handsome young man who has worked for almost a decade on MSL's launch, cruise, and approach phases. His role in these final moments of landing is largely one of quiet observation, watching data he knows are already fourteen minutes old, delayed by the huge distance between Earth and Mars. He summarized it well: "It's like taking the SAT [college entrance exam]—you've taken the test, you are done. Nobody will tell you the score right then, so you have to wait. You're nervous. Something happening now could change the outcome of your life." And he couldn't be more correct, except that his life will change in ways far different than he expects, including a couple of hundred marriage proposals via Twitter and a future visit to the White House to meet the president and First Lady. But that is some time off, and at the moment he is fixated on the screen in front of him.

But not everyone involved with the mission can fit in mission control. A building away, Ashwin Vasavada sits, also intently eyeing a computer screen. He is, along with Joy Crisp, a deputy project scientist on MSL. He is also a spectator at this point. Curiosity carries experiments that he and Joy have helped to shepherd through the process of construction, testing, installation, and launch, as they oversee the larger science team behind the MSL mission. "I feel like I'm enabling almost 48 scientists and a spectacularly good mission with a lot of scientific integrity," he comments. "I like to put my heart and soul into making sure we do good science." Now, like Grotzinger, all he can do is watch, a helpless captive to events far away, above another world, as the much-anticipated entry, descent, and landing (or EDL) sequence begins.

Vandi Tompkins, slated to be one of a small group of rover drivers and programmers for Curiosity, is also waiting out the landing as an observer. As an engineer, she has ultimate faith in the machine and her comrades who designed it. As a PhD in advanced robotics, she also has a deep attachment to the machine in a way that few would understand. And as a woman who came to the United States from India to make her way into the stratified world of planetary exploration, she can sometimes scarcely believe her good fortune to be here, on this program, at this moment. The next few minutes may well determine her fate for the next decade.

And this is it—the by now well-known seven minutes of terror, made famous by the video of the same name that went viral a couple of months earlier. On cue, MSL spacecraft plunges into the thin Martian atmosphere after a largely uneventful journey lasting nine months. Much like war, robotic spaceflight is often characterized as long stretches of boredom followed by moments of intense terror. The spacecraft will automatically go through the intricate ballet of landing in a small target area on a planet far, far away. When it is over, the signals describing success or failure will still be making their way back to Earth at the speed of light; during landing, MSL (and the Curiosity rover ensconced within) is completely on its own. Grotzinger, Manning, Ferdowski, Vasavada, Tompkins, and thousands of others will still be staring at computer screens, continuing to count the seconds and ticking off the milestones as if events were still unfolding. In short, regardless of Curiosity's fate, people in Pasadena and all over the world will continue watching and waiting for the signal that will free them to breathe again.

High in the skies of Mars, following a roughly equatorial trajectory, MSL hurtles toward the Martian surface. The onboard computer, a radiation-hardened version of an early-2000s Macintosh PowerPC chip, is processing incoming data like mad and adjusting flight parameters to match. A firing of a thruster here, a guidance adjustment there. There's not much time left to correct anything, though, for the guided portion of entry—where MSL glides across the skies on its heat shield, adjusting course continuously—is just about over.

On cue, the huge parachute deploys, unfurling spectacularly above the spacecraft while it is still traveling at supersonic speed. The craft begins to slow and angle toward the ground. High above, in Martian orbit, one of JPL's other robotic explorers, the Mars Reconnaissance Orbiter, snaps a photo of

a tiny spacecraft dangling from a parachute. That it captures the lander at all is a near miracle, for ~~was being aimed in advance purely by sophisticated calculations performed by JPL flight engineers~~. The resulting image was a remarkable bit of space-age orchestration.

Down, down Curiosity drops, until—while still high in the air and in an apparent contravention of logic—it separates from the parachute. But seconds later, powerful onboard rockets fire, further slowing the spacecraft.

At JPL, a room full of men and women, mostly in their twenties and thirties, monitor the hundreds of systems and subsystems critical to a successful landing. The old folks—the ones over fifty—are mostly in the back row. This is a young person's mission.

Adam Steltzner, the forty-nine-year old rock 'n' roller primarily responsible for getting Curiosity onto the surface of Mars safely, paces like a lion on the hunt behind a row of intent controllers. He has been likened to Elvis with a doctorate in engineering, and now he monitors the consoles and the big picture. His pace quickens as the displays show MSL getting closer to Mars.

Events are occurring rapidly. Data from multiple onboard radars are guiding the machine to landing inside Gale Crater, and within that into a landing zone called a “landing ellipse” due to its shape. It is just over five miles in width, and its long axis is twelve miles. It is the most ambitious and accurate landing attempt yet, and from what the folks back home can see, as smooth as any to date. The rocket pack/descent stage and its associated winching mechanism, collectively dubbed “sky crane,” is working perfectly. In the final phase of what looks like a landing cycle designed by Ruben Goldberg, or possibly Wile E. Coyote, the descent stage slows to a walking pace and sky crane begins to winch the Curiosity rover down via four cords, each about sixty feet long. It is by far the most complex interplanetary robotic undertaking in history.

Manning is at one of the rearward consoles, not quite with the old guys in the back but not with the youngsters at the front either. He's watching the system he led his team to create—not just sky crane but the whole landing system—and probably also thinking about the last-minute fixes he applied to Curiosity while it was already bolted atop the rocket, ready to launch. It was a close thing.

Al Chen is on the console as the operations lead for this critical phase of the mission and also the voice of MSL tonight. He is in his thirties, is married with three kids, and is normally a pretty unassuming guy. MSL has thrust him into the limelight, and his announcements come over the speakers in hushed, almost-unbelieving tones: “Sky crane deploying.” It's JPL shorthand for “Holy —! This damn thing works!” A collectively held breath releases and some scattered cheering issues forth, followed by applause. Then, a few moments later: “Touchdown confirmed—we're safe on Mars!”

The room goes nuts as controllers, scientists, engineers, and other associated JPL'ers erupt in heartfelt cheers. In a nearby building, inside the press room, normally stoic and hardened reporters from the major TV networks, newspapers, and periodicals just lose it. It is true pandemonium. Curiosity has arrived...and done so to perfection.

On Mars, MSL's rocket pack, comprising the engines and the navigational unit that brought the rover to the surface, has long since detached and flown off to crash a few miles distant. After a muffled thump, silence returned to Mars.

It will later be concluded that the rover alighted about 1.5 miles from point zero, well within the landing ellipse. It's a true pinpoint landing, as close to Mount Sharp, their primary objective, as anyone dared to hope.



Fig. 2.1. THE VOICE OF EDL: Al Chen on the console shortly before touchdown, narrating the entry, descent, and landing phases like a play-by-play. *Image from NASA/JPL-Caltech.*

Once the machine is secured, a jubilant EDL team bursts forth from mission control, heading to the press room (in more normal times, JPL's auditorium), wearing matching powder-blue polo shirts and chanting “Eee-Dee-El! Eee-Dee-El!” in triumph. It is a rare moment of collective joy and outright raw emotion for these normally reserved people as they literally dance across the university-like quad. And it is well deserved.

Grotzinger smiles broadly, hugs a few people, pumps even more hands, and prepares for the press conference soon to follow. Rob Manning is mobbed by well-wishers, smiles like the punch-drunk engineer he is (he has been at this for eight intense years and has not slept much for almost thirty-five hours), and heads off to a series of interviews. Joy and Vandi hug coworkers and then begin to think ahead. Unlike Grotzinger, they do not have the camera lights and questions of a press conference to distract their attention from the challenges that lie before them. Both return to thinking about the larger mission—the upcoming milestones needed to ensure that the rover can accomplish its primary objectives.

Bobak Ferdowsi takes a moment to check his smartphone and discovers that in the past few hours he has become an Internet meme and instant sensation. But there is not time for that now; he has people to congratulate and a rendezvous with a pillow. Ashwin feels the glow begin to fade a bit. He is responsible for coordinating the moment-to-moment science activities of the mission, a massive job, and tomorrow things will get very busy regardless of how much—or how little—sleep he manages to get. Nonetheless, he will remember the landing as one of the high points of his life.

Hundreds of others on-lab, and hundreds more offsite, pop champagne corks and toast success tonight. They enjoy the moment, as well they should, for tomorrow engineers, scientists, and managers begin a multimonth grind known as Mars Time—their days will match Martian days, known as “sols,” which add forty minutes to each twenty-four-hour Earth day. The world will soon become a surreal, time-shifted place to the bleary-eyed participants in Curiosity's mission. But tonight is for celebration.

On Mars, the dust has settled around the unmoving rover. A few clicks and whirs can be heard from the inside as the Hazcams pop open lens coverings and begin imaging the immediate surroundings. Other mechanisms restrained for landing free themselves, and heating systems power on for the coming Martian night ahead.

Curiosity has arrived, and the greatest adventure Mars has known is about to begin.

CHAPTER 3

A LONG ROAD TO A RED PLANET

Exploring Mars has been a passion of earthbound scientists for centuries. Few thought of actually *going* there until the mid-1800s, but notions of Mars as a planet where beings might exist date back nearly two hundred years earlier. Christiaan Huygens, a Dutch astronomer and cosmologist, published a book in 1698 that speculated about life on the red planet. This idea bloomed in the 1800s, but it would be much later that the idea of exploration of the planet with humans was taken seriously. The idea of using machines to do so came later still. Many early visions harkened back to the golden age of earthly exploration, which was not conducted by robotic machines—there weren't any to do so yet. These voyages were accomplished by *men* in square-rigged ships that traveled to distant and forbidding places to plant the flag of their nations in faraway lands (and often cause disease and destruction to rampage through the native inhabitants). Surely, the thought went, the exploration of Mars would be accomplished in a similar fashion—by men (probably military) in rocket ships.

While many over the centuries thought of traveling to other worlds, it was not until Mars was understood as a planet—that is, a *place*—that these notions gained any sophistication. But even very early observers with scientific grounding began to notice things about Mars that were telling. In the fourth century BCE, Aristotle noted that Mars was occulted by the moon—Mars clearly passed behind it. This led him to the conclusion that Mars was farther away from Earth than the moon was. Which, this may seem painfully obvious to us today, at the time little was known about *anything* in the night sky; certainly Mars had not yet been identified as a world.

The earliest observations of Mars centered on its color. Few objects in the night sky exhibited any hues other than white, and none were as ruddy as Mars. So it is not surprising that the planet became intimately identified with all things violent—war, famine, and death. The various mythic figures that Mars became associated with were murderous at worst and portended a bad day at best. It was the Hannibal Lecter of celestial bodies.

Ancient Babylon, Egypt, and China all had deities associated with Mars. To the Babylonians, Mars was associated with Nergal, a deity of fire and destruction. To the Egyptians, Mars was Horus the Red, associated at first with the harvest, but later with violence. China and other Asian cultures saw the planet as representing fire and all its unpleasant associations, and eventually with mayhem. You didn't want Mars (or Nergal, Horus, or even the combustible Asian version) dating your daughter.

The Greeks also worshipped Mars as a god, named Ares, who carried with him the usual unfortunate associations. Though he was the son of Zeus, king of the gods, and his wife Hera, who was beautiful and wise, Ares was a wayward scoundrel and simply could not live up to his parent's accomplishments without getting into trouble. Perhaps the fact that Hera was also Zeus's sister may have been a factor—a troubled gene pool indeed.

The Romans had a similar interpretation of the god they renamed Mars. While they imported his virtues—or lack of them—from the Greeks, in Rome the red planet's penchant for violence was considered a big plus. Since the empire would conquer and rule by force, paying homage to Mars's psychotic tendencies made a certain amount of sense. The one thing the Roman Mars did have over his predecessors was a measure of intelligence—in many previous iterations, he was downright doltish.

the Romans made him a violent and warlike being, they also made him a smarter one. He went from being Steinbeck's Lennie to TV's Dexter in one sweeping cultural iteration.

Then Ptolemy, a Greek living in ancient Alexandria, came along in the second century CE and (surely with the best of intentions) created a model for the solar system that brought some apparent order to the chaos seen overhead, but also gummed up Western astronomy for well over a millennium. In his universe, Earth was at the center of all things, and the lights observed in the sky moved around it. These other bodies were affixed to spheres—unimaginably huge, crystalline, transparent ones—that rotated, imparting the motions observed. The obvious planets, those observable by the naked eye (Mercury, Venus, Mars, Jupiter, and Saturn), each had a crystal sphere of their own in logical order. The moon's was closest to Earth, the sun fell between Venus and Mars, and the final sphere was the one upon which the stars were mounted. This system, logical from a contemporary observer's viewpoint, was to remain fixed in place (just as Earth was, at dead center) for about 1,200 years. It was one of science's longest-held misconceptions, but at least it was an attempt at science. Despite this valiant effort at understanding the solar system, the broader culture that surrounded Ptolemy continued to see gods in the heavens.

Mars continued to be the scourge of the cosmic playground through medieval times, and not until 1543 did the red planet really become a *what* rather than a *whom*. Nicolaus Copernicus, a brilliant Polish astronomer, was finally able to build a mathematical model that supported a heliocentric system, that is, one with the sun at the center of the solar system (in fact, the sun was the center of the entire universe so far as he was concerned, but that inconvenience was cleared up much later). The almost a half century later, Johannes Kepler, a German scientist who worked out the laws of planetary motion, further developed the mathematical certainty of a sun-centered system.

About the same time, Galileo Galilei began looking the planets through his telescope, observing among other things, the distinct phases of Venus. He was also able to see the planets as objects, not just as points of light, and their massiveness and motions under a heliocentric model made even more sense. He couched his opinions somewhat, though, as he had already endured enough torment at the hands of the Renaissance church to make him gun-shy. Speaking openly of his ideas turned out to be a recipe for papal investigation and, ultimately, a lifetime of house arrest. Sometimes it sucks to be too far ahead of your time.

It was not until the 1800s that Mars truly came into its own as a planet, apparently similar to Earth in the minds of astronomers. While many were using telescopes at this time to observe the planet, notable among them was Giovanni Schiaparelli. During Mars's closest approach to Earth in 1877 (when the two planets' orbits bring them closest together, an event called "opposition"), he began a series of extensive observations that resulted in one of the first true maps of Mars. Schiaparelli invented a vast network of continents and seas for the red planet, further adding to its Earth-like mystique. Mars was continuing on its long journey to being a world, a place, that could be explored and—possibly—inhabited.

Among Schiaparelli's unintended "gifts" to Western science was the misinterpretation of his observation of linear features on Mars that he called *canali*. While in his native Italian this merely describes a channel (natural or not), to the English-speaking ear this sounds like "canal," and in a profound case of mistaken identity, a great controversy began.

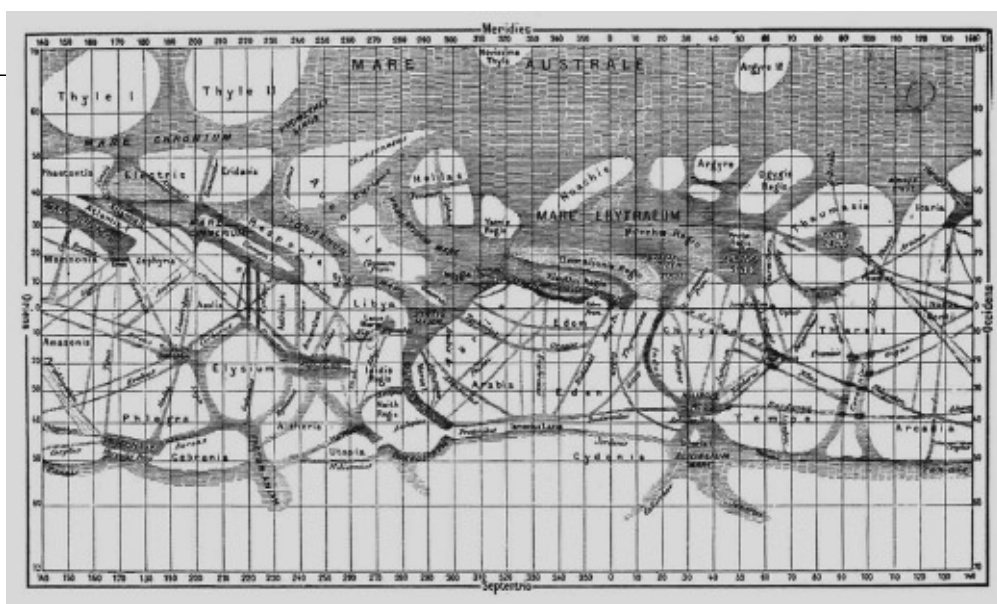


Fig. 3.1. *PLANETA MARTIS*: Schiaparelli's Mars map of 1877 demonstrated far more detail than he was able to see through the telescope. Many of the lines seen here did not exist, and were either figments of his imagination or the possible result of eyestrain. Regardless, these charts had a profound impact on popular thinking about Mars and strengthened the tradition of naming features in Latin. *Image from NASA.*

This misinterpretation was picked up and vastly amplified by an American amateur astronomer named Percival Lowell. Born of a wealthy Boston family with a fortune made in the textile business, Lowell spent years in Asia making a mark as a chronicler of Japanese culture before taking astronomy seriously (he already had a degree in mathematics from Harvard). Once bitten by the celestial bug, however, he was unstoppable. He moved to the Arizona territory in 1894 and built an observatory in Flagstaff with the stated aim of observing Mars. Lowell commissioned one of the larger refracting telescopes of the time, an instrument twenty-four inches in diameter, to facilitate his Martian observations.

It's interesting to note that Schiaparelli and Lowell were somewhat contemporary to one another with their respective peak activities being offset by about twenty years. When confronted with Lowell's interpretations of his work, initially Schiaparelli was somewhat miffed, but over time he softened and moved from denial to ambivalence, then even to a certain level of enthusiasm, about the idea of artificially created canals on Mars. Even then, people seemed to know the value of good P. T. Lowell was the P. T. Barnum of Mars, and if you can't beat 'em...

Lowell took to his new life's purpose with relish. Over the next fifteen years, he spent countless nights in his cold observatory, observing and sketching Mars. Lowell also saw the elusive canals but perceived of them differently than did Schiaparelli. He charted these illusory features in much greater detail, numbering them and striving to discern some logical order to their design and placement. From these extensive and painstaking (and largely imaginary) observations, he began to develop his own theories about Mars and what—or *whom*—might exist there. Perhaps most profoundly, rather than limiting his ideas to scientific circles (where he met with opposition to his unique notions), he published a series of popular books between 1895 and 1908 that struck a chord with the general public.

These widely read books built a public case for intelligent life on Mars. Going far beyond mere observation and charting of the planet, Lowell imagined a vast civilization with a form of planetary government (after all, the rulers would need to have global reach to build such a vast network of canals). This technologically brilliant Martian empire was working against the clock to save the dying world as the water vanished. Mars was much older than Earth, he reasoned, and was thus farthel along in its planetary evolution. It was cooling and was water-starved, and the Martians had built this vast network of canals, complete with pumping stations, locks, and other manipulations, to bring

water from the poles of the planet to its parched temperate regions. It was an elaborate mental invention, and the romance of these ideas was to last for a half century in the public mind. Lowell's ideas about how Mars lost water were not really wrong, they were just off by about 3.5 billion years. The rest, engaging though it might be, was just so much mental popcorn.

While it is easy to dismiss Lowell's fanciful ideas today, reading his books (not a trivial undertaking) does impress one with the (admittedly misplaced) rigor of his thinking. If one starts out by accepting the idea that his Martians might actually exist, he builds a convincing case, using whatever scientific ideas were supportive to his arguments. While this is not a true implementation of the "scientific method," it was an attempt at building a logical view of another culture that held some allure.

Although few discuss it today, while Mars was wiling away the early twentieth century as a planet inhabited by parched, clever engineers, Venus was thought to be a sunny, humid jungle world. Little was known about the planet, and virtually nothing could be observed beneath its opaque cloud cover. Well into the 1950s, popular culture (aided by the likes of Edgar Rice Burroughs, who had his wars with both Mars and Venus), Venus was the jungle world, with riotous plant growth and steaming swamps. The truth was even more shocking than it would be with Mars, as Venus was ultimately unveiled as a hellishly hot, sterile, acidic nightmare.

During the first half of the twentieth century, other scientists spent years observing Mars via the telescope, often striving to disprove Lowell's assertions. Using spectroscopes as their primary weapons, various observers were able to discern that there was far less water in the atmosphere than Lowell had theorized, and that the air was much thinner than appropriate for his Martian civilization. Lowell's romantic world was beginning to slip away.

This work was, however, restricted to the evidence of the telescopic eyepiece and other earthbound methodologies of observing Mars. Under optimal conditions, with a large, well-placed telescope, and even during its closest approach, the best image of the red planet is still subject to the vagaries of what astronomers call "seeing." Earth is covered in a blanket of air, turbulent and fickle, and air is dense enough to distort light. So even on the best of nights, the small, dim, red image of Mars swims in and out of focus, bending and flexing at the whims of the atmosphere. Profound or accurate observations of the Martian surface are difficult at best. The use of the spectroscope, a prismatic device that splits the light from a planet or star into its constituent gasses and elements, strove to overcome this limitation but was able to supply only a limited range of answers. Later, radio telescopes, unaffected by the optical properties of the atmosphere, were utilized to explore Mars but were also limited to what they could "see" on a planet and had other issues with Earth-based interference and background noise from space. In short, to really understand Mars, we would have to *go there*.

This idea of traversing the great blackness between Earth and Mars had appealed to many over the years. Fiction treated it in various ways: In the worlds of Edgar Rice Burroughs, writer of the John Carter books, all you needed to do was fall asleep in the back of an enchanted cave in the Wild West and * poof * you awoke on Mars. Later on, the brilliant Russian Konstantin Tsiolkovsky and German like Hermann Oberth speculated on the use of rockets to carry people into space and perhaps even on other planets. They were widely dismissed as cloudy-minded visionaries at best, crackpots at worst.

With the advent of modern rocketry in the twentieth century, these simple ideas became elaborate plans. No less a personage than Wernher von Braun, alleged Nazi and father of the Saturn V rocket that took America to the moon, labored on the problem. In his 1953 book *Das Marsprojekt (The Mars Project)*, von Braun envisioned an armada of ten enormous spacecraft assembled in Earth orbit by reusable space shuttles. This fleet would embark sometime around 1965 for a three-year round-trip including a yearlong stay on the surface of the planet.

The elaborate scheme was presented in a simplified form in *Collier's* magazine and generated

sample content of Curiosity: An Inside Look at the Mars Rover Mission and the People Who Made It Happen

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