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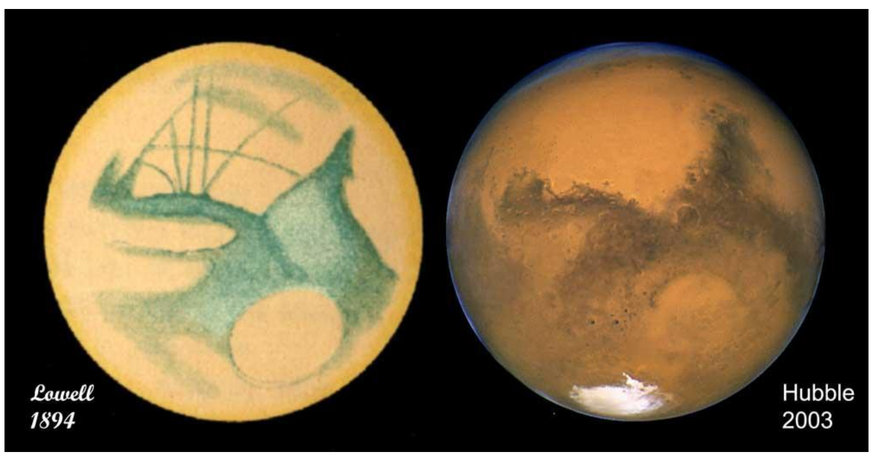
Follow the Water: The Grand Canyon and Mars



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Assembly Room, A. K. Smiley Public Library

Follow the Water: The Grand Canyon and Mars
By Tyler Nordgren

Summary: A paper intended for the popular audience describing the scientific and historical connection between research on the planet Mars and the landscape of the American Southwest. An overview of mars research from Percival Lowell to the recent NASA Mars rovers mission is given with an analysis of our understanding of the role of water in the formation of the martian surface.

Keywords: Mars, Grand Canyon, Percival Lowell, John Wesley Powell, American southwest, water

"All this is the music ofwaters."

— John Wesley Powell, 1895

"Irrigation, and upon as vast a scale as possible, must be the all-engrossing Martian pursuit."

— Percival Lowell, 1895

"Follow the water."

— NASA, official Mars exploration theme, 2003

Tonight Mars rises at sunset. Every two years it does this as the Earth overtakes and draws close to its slower cosmic kin. At these times Mars grows brighter than any other star in the sky. Then, just as quickly, the process reverses; the Earth sweeps onward, and Mars fades away to become one more light in a cold starry sky. For those few months that we spend under a foreboding blood red star, it's no wonder the planet was named for the god of War.

But Mars is no harbinger of doom; it's simply a planet, the fourth planet from the Sun. It's smaller than the Earth, with a surface area a little more than a quarter that of the Earth's - or roughly equal to the dry land mass of our own world.

Unlike all other heavenly bodies (save the Moon) Mars reveals a landscape to the telescopic observer. During each near encounter even a small telescope reveals a white

polar cap of ice or snow. At these times, it is easy to see through telescopes that Mars is a

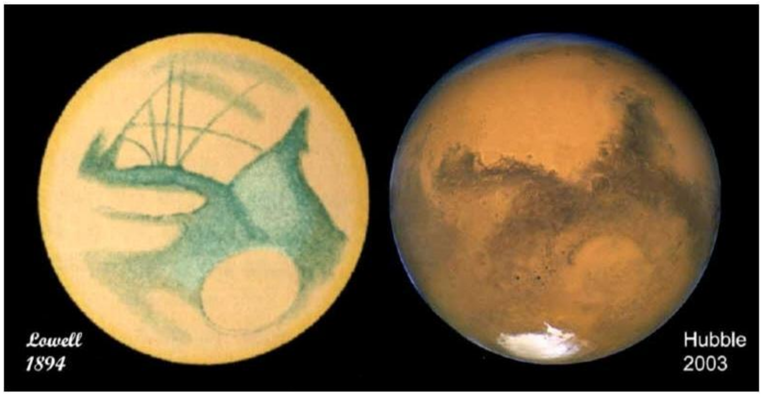
reddish-ocher world with occasional markings of a darker blue-green. The movement of these markings across **the disk reveals Mars** has a day only 40 minutes longer than ours. **Their** movement also shows that Mars' axis of rotation is tilted only a few degrees greater **than our own. Mars therefore goes through its seasons, just as we** go **through ours.**

From our telescopes we can see that **Mars has an atmosphere. While** it is thinner **than ours, it is composed in large part of water vapor that keeps the Martian climate relatively mild though no trace of snow or ice is ever seen outside the polar caps.** Observation of **these** caps and the blue-green regions show they change in size, darkness **and color with the seasons. From winter to summer the polar cap shrinks. As it does so, a** network of globe girdling lines becomes apparent and the equatorial blue-green regions **grow in size and deepen in color.**

From all these observations we may logically conclude that Mars is a **warm, dry,** desert world where a globe **spanning network of canals has been built to irrigate vast agricultural regions sustaining a civilization that, by its engineering skills, must be greatly** superior to our own.

This is the state of our knowledge of Mars, as observed and deduced by the most prominent astronomer of today.

Provided that by "today" I mean 1895. A little over a hundred years later our view **of Mars could hardly be more different.**



Mars: sketch by Percival Lowell, 1894; photo by Hubble 2003

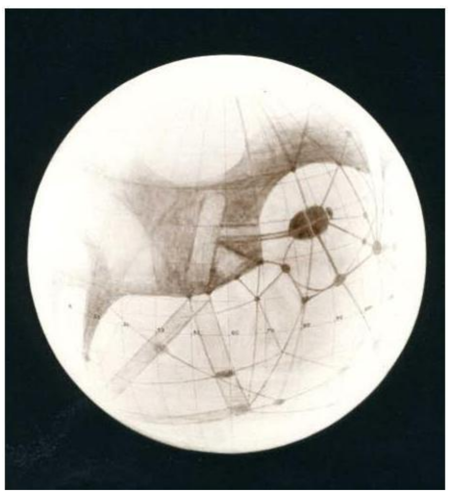
In the spring of 1894 Percival Lowell, gentleman astronomer, and son of one of the rich and mighty "Boston Brahmin" families of Massachusetts, built an observatory in Flagstaff, Arizona Territory, for the purpose of observing Mars. To be an astronomer at the telescope a hundred years ago is almost nothing like the practice today. On a clear night in a modern observatory, I sit in a warm insulated control room. I direct the telescope operator to point the telescope at my target then command the computer to begin my photographic exposure. Shutters on a digital camera open to allow the faint light of stars or galaxies to slowly accumulate over many minutes or hours. This faint dribble of light eventually builds up detailed images of distant sights that can be measured and checked, quantified and calibrated at my leisure over the following hours, days or years.

Lowell had none of these. At those moments of exceptional clarity in the atmosphere, where the image of Mars in the eyepiece suddenly crystallized into sharp relief, Lowell had to quickly sketch what he saw before memory and image faded and blurred. To add insult to injury, Mars' close approach in 1894 occurred in winter. Clear night skies in Flagstaff are exceedingly cold and in these conditions Lowell spent many hours in the open at his telescope's eyepiece. A dark winter's night became a long, cold

collection of short, sharp sights, relegated to paper; the precision of the recording wholly dependent upon the artistic skill of the observer. Long after the night was over, the only record of what was seen was the artist's sketch, the image itself existing only in fading memory.

To make matters worse, the objects of most importance weren't the big obvious sights, visible to all, but rather those elements right at the limit of what could be perceived. A feature's importance to science therefore took on an inverse relation to its ability to be seen. What were faint, even invisible markings under normal conditions soon became a network of connected lines, geometric shapes, and oval intersections, completely girdling the slowly spinning planet.

These were the canals of Mars, and astronomers of the day quickly became grouped into those who could see them and those who couldn't.



Mars canal map by Percival Lowell.

Now it was not lost on Lowell that the Mars he saw in his mind's eye, if not through his telescope, bore a strong resemblance to the countryside beyond the borders of Flagstaff. The cold, high altitude summits of the San Francisco Peaks, visible from his

observatory home, provided evidence to his mind for why life could easily survive the cold winters and low atmospheric pressure he calculated for Mars. In his 1906 book, *Mars* *and Its Canals,* Lowell described the similarity he saw between Mars in his telescope and the distant deserts of the Four-Corners region, "The pale salmon hue, which best reproduces in drawings the general tint of [Mars'] surface, is that which our own deserts wear. The Sahara has this look; still more it finds its counterpart in the far aspect of the Painted Desert of northern Arizona. To one standing on the summit of the San Francisco Peaks and gazing off from that isolated height upon this other isolation of aridity, the resemblance of its lambent saffron to the telescopic tints of the Martian globe is strikingly impressive."

Painted Desert

For Lowell, this similarity was not by chance, but rather a reflection of the natural lifespan of the planets. From simple calculations Lowell showed that the smaller a planet, and thus the weaker its gravity (the force of gravity on Mars is only 38% of our own), the quicker its atmosphere should escape away to space and thus its seas evaporate and its

surface turn to desert. Lowell then made the leap to advocating that this is the fate of all planets. Thus by understanding Mars and the differing evolutionary states of the planets, he argued that we learn more of our own planetary fate.

Lowell saw evidence of this Martian "Death by Desert" in the Great Salt Lake of Utah with its surrounding dry salt wastes and ancient shorelines in the nearby hills. In his book, *Mars As the Abode of Life,* published in 1908, Lowell presented further evidence of the growing desertification of the Earth in the form of ancient fossilized trees preserved in what is now Petrified Forest National Park, 100 miles east of Flagstaff.

> Now these desert belts are widening. In the great desert of northern Arizona the traveler, threading his way across a sage-brush and cacti plain shut in by abrupt-sided shelves of land rising here and there some hundreds of feet higher, suddenly comes upon a petrified forest.... The land which once supported these forests is incompetent to do so now. Yet nothing has changed there since, except the decreasing water supply.... Proof of this is offered by the great pine oasis that caps the plateau of which these petrified forests form a part, and is kernelled by the San Francisco Peaks.... Two thousand feet upward the verdure-line has retreated since the former forests were.

All around him Lowell saw Mars, but a Mars the Earth was slowly becoming.

By the publication of Lowell's *Mars* in 1895, the nineteenth century had seen the greatest mass movement of humanity in recorded history. Lowell's relocation from Massachusetts to Arizona Territory was part of this headlong westward migration and eventual settlement of what was known as the Great American Desert.

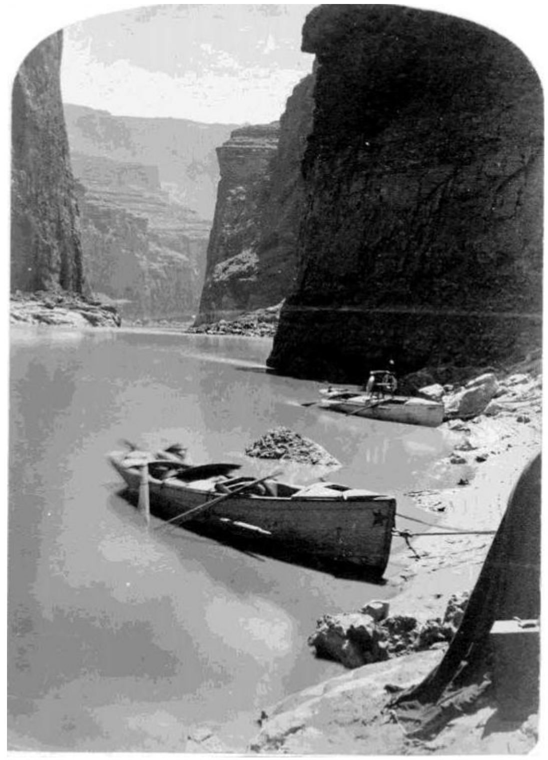
But the western American interior is an arid land. For those who live there, to *waste* water means to let even a single drop of water go un-used. However, in the forty years previous to Lowell, it was the subject of conjecture that the very act of "opening" the West with farms would bring the rains that would transform the bone-dry expanse

into a new Garden of Eden. "Rain Follows the Plow" was the actual climatological claim' whereby Nebraska and Arizona would soon be as green as New York and Alabama. This bizarre conclusion was based upon nothing more than the unfortunate coincidence that the beginning of the westward expansion of the late 1 870s and `80s was followed immediately by an extended period of above average rainfall that had never been seen before (or since).

And, as fate would have it, the drought that inevitably followed was in full force when Lowell arrived in Arizona Territory to build his observatory.

But there'd been people living for thousands of years in the parched country the white men had just recently entered. John Wesley Powell – a retired Civil War Army Major, geologist, and university professor — set out from Green River, Wyoming in 1869 to explore the geology and people of the Colorado River canyon country. Powell and his nine-man expedition were the first white men, and for all we know the first people at all, to navigate the length of the Colorado River canyons by boat. During his two historic expeditions through the Grand Canyon Powell mapped, measured and wrote about the spectacular landscape, all the while learning about the people who made this land their home. Powell was intensely curious; what were they like, what were their customs, how did they survive and prosper in a land of such magnificent desolation?

For a full account of American preoccupation and policy towards water in the West read Marc Reisner's *Cadillac Desert: The American West and its Disappearing Water.*



Grand Canyon photo, Second Powell Expedition

What Powell found, he spent the next thirty years popularizing to the country. The same 1895 that saw Percival Lowell publish the first of his wildly popular accounts of an ancient civilization coming to grips with the arid desert landscape of Mars also saw Powell publish *Canyons of the Colorado,* his wildly popular account of his exploration of the Colorado River, the landscape, and people right outside Lowell's observatory doors.

"In centuries past," Powell wrote, "the San Francisco Plateau was the home of pueblo-building tribes, and the ruins of their habitations are widely scattered over this elevated region." Just a few short miles from Lowell's own observatory, Powell described cliff ruins of a "vanished" people that "built stairways to the waters below and to the hunting grounds above" in what is today Walnut Canyon National Monument. Farther south of Flagstaff, where the last great tributary of the Colorado drains much of present day Arizona and western New Mexico, Powell found:

> In the valley of the Gila and on its tributaries from the northeast are [the tribes of the] Pimas, Maricopas, and Papagos. They are skilled agriculturalists, cultivating the lands by irrigation. In the same region many ruined villages are found. The dwellings of these towns in the valley were built chiefly of grout, and the fragments of the ancient pueblos still remaining have stood through centuries of storm.... The people who occupied them cultivated the soil by irrigation, and their hydraulic works were on an extensive scale. They built canals scores of miles in length and built reservoirs to store water.

The American West in which Lowell made his observatory and observations was therefore awash in stories of ancient civilizations, canals, and the ongoing battle for water against the all consuming desert. Whether Lowell fully realized it or not, the "logical" conclusions he drew from his observations were colored by the world in which he lived and worked. Desert planet, drought, ancient civilizations, engineering marvels, and canals; Earth or Mars? Who's to say which world he was really describing?

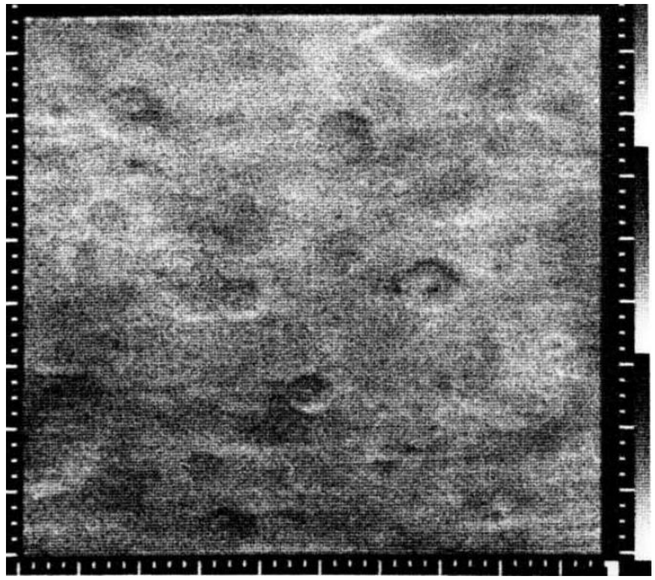
What is unambiguous is that thanks to Lowell, Martian canals were seared into the public consciousness. The Mars that the world saw, heard, and read about in 1898's *War of the Worlds* by H. G. Wells, and 1912's John Carter of Mars stories by Edgar Rice Burroughs, was unmistakably Lowell's Mars.

As a result, for much of the early 20th century, it was possible to look into the night sky at the ominous red planet and know, actually know, that you were seeing the abode of intelligent alien life.

I can't imagine what that must have felt like, and I don't know an astronomer today who wouldn't give anything to be able to feel that way again.

Unfortunately, when Mariner 4, the first Earthly spacecraft to fly by Mars, sent back its first photos they showed a dry, dead, cratered world like the Moon.

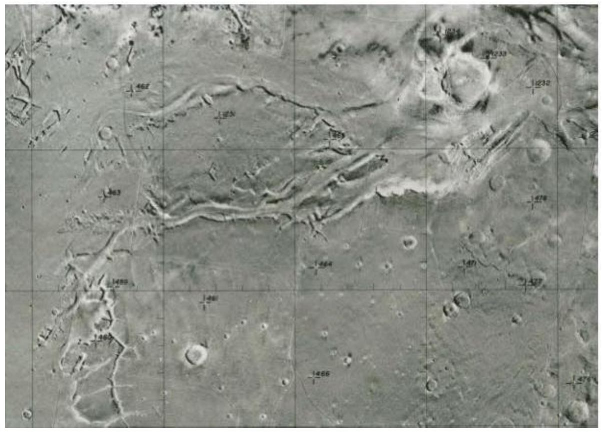
So much for Lowell.



Mariner 4 photo of Mars

But Mariner 4 (as well as the later Mariners 6 and 7) all flew past Mars's southern hemisphere. If the only thing we knew about the Earth were gathered from a fleeting glimpse at our own planet's southern hemisphere, we might suspect our planet was covered by nothing but water.

When Mariner 9 went into orbit around the Red Planet four years later, it was for the express purpose of carrying out the first global reconnaissance. While its cameras certainly confirmed craters aplenty, the new views of the northern hemisphere revealed what appeared to be vast, dry riverbeds and canyon networks like those seen from a typical transcontinental flight over the American southwest. In addition, there in the window were volcanoes larger than any on Earth and a great, *grandest* of canyons as long as the continental United States. While the planet might appear lifeless today, orbital evidence showed a world that may not always have been so.



Mariner 9 photo of Martian channels.

A hundred years after Lowell wrote Mars, I was an astronomer at the very same observatory. During my weekends, I used to hike through the countryside of the Grand Canyon region, seeing the very places Lowell described a hundred years before. In that time, between Lowell and me, humanity had successfully landed only three spacecraft on the surface of Mars. In every camera frame was a landscape reminiscent of the dry, desert, red rock country I was seeing, just like Lowell had described (minus the canals).

In 2003, during the unusually close opposition, NASA was planning to send a pair of rovers to Mars. Like Powell over a hundred years before, we would finally be able to get out and head to the horizon and explore. A former professor of mine at Cornell University, Steve Squyres, was the lead scientist for the rovers and he asked me to help turn their color camera calibration targets into sundials as a way of reaching out to school children about the excitement of space exploration. So as I hiked through the landscape of Lowell and Powell, through the canyons and monuments with which both were so familiar, Mars was on my mind. How far did the similarities between Earth and Mars actually extend? Looking around, just how much Mars could I see and had it always been this way?

Mars sundials on Spirit and Opportunity Rovers

Today is a hot sunny day in the heart of the canyon country of northern Arizona. My boots are powdered orange from a trail through towering monoliths - giant fins of rust colored sandstone that border a mostly dry wash. In every direction I see red, layers and layers of it. Salmon-colored sand trickles off buff sandstone ledges bordering a pink and rosy trail beneath my feet while overhead stand gargantuan blocks of crimson stained by desert varnish in streams of maroon and purple.

These awesome stone sentinels are an iconic vision of this country visible in everything from John Wayne movies to Road Runner cartoons. Even though no Martian lander or rover has yet photographed a towering landscape like what I see around me. it is not for its absence on the Red Planet. Rather, NASA scientists and engineers are conservative with their expensive spacecraft, and have taken great care to land them where they have precisely because they are devoid of towering buttes and breathtaking cliffs. But orbital imagery shows they are there if we could but drive far enough to visit them.

To experience Mars in person is a dream I have had since I was a boy. Long ago it became clear it would not happen for me. But to do so now, through the knowledge gained from the spacecraft that have gone there, all I need do is mentally manipulate the view before me and create, step by step, a Mars of my imagination.

Red rock panorama on Earth

First, take away the majority of the atmosphere and all the oxygen I breathe. As distressing as this might personally be, another more visible transformation suddenly takes place. Light from the Sun is composed of all the colors of the rainbow. On Earth, oxygen molecules in the air scatter the blue end of the spectrum in different directions. This blue light bounces from molecule to molecule before eventually finding its way towards the Earth and our eyes. From our perspective on the ground, we see this blue light reach us from every part of the sky, and thus the sky looks blue. With virtually no atmosphere on Mars: good bye blue sky.

Next, with only one hundredth the atmospheric pressure of Earth (and correspondingly little of the greenhouse gasses that keep us warm) the surface temperature drops dramatically. Move the Sun 50% farther away, and it gets even worse. Only in summer near the equator do the temperatures on Mars top the freezing point of water. The humidity plummets, the atmosphere becomes bone dry and the puffy white clouds above me disappear. There are still clouds. but they are high thin clouds of tiny ice crystals.

The pressure and temperature over the rest of Mars means any water within a few meters of the surface is frozen solid, so there are no puddles, streams, or rivers. The tiny trickle of water at my feet from yesterday's spring rainstorm evaporates instantly as if it was never here, as indeed rainstorms on Mars may never have been.

With the liquid water, take away everything green and growing. This last one is a shock. Most places on Earth that are described as dry, arid, desolate, desert, usually have some kind of plant life, be it ever so drab or humble. Look around you and imagine your landscape, not just without any trees, eyecatching flowers, or bushes, but with nothing. In fact, get rid of most of the dirt you see as, in addition to the minerals it contains, the soil beneath your feet is composed largely of decayed plant matter and moisture.

What then is my new Martian ground covered with? Rocks. Big rocks, small rocks, crushed rocks, pulverized rocks, powdered rocks, and dust. The last few billion years of sandstorms have blasted away at the stony landscape, weathering cliff and mountain down to pebble and grit. And without rain to wash away dust and cause it to clot, it works its way as a fine powder into every microscopic nook and cranny across the entire planet's surface.

Iron in the dust reacts with what little oxygen there is in the atmosphere (a byproduct of ultraviolet light from the Sun splitting apart the components of the thin carbon dioxide atmosphere) forming iron-oxide — rust — that turns the whole world red. Here, at last, is a change I don't need to make to my surroundings. The red rocks of Mars are red for the same reason the rocks are red in the Grand Canyon and surrounding country. Mars is Moab made global.

In addition, without any moisture to hold and clump the Martian "soil," the loose red powder fills the air and is picked up by the winds. Great globe-girdling dust storms blow the iron oxide particles high into the thin Martian atmosphere, turning the sky forever pink and ochre. The Technicolor palette of the southwest transforms Mars to variations on a russet theme.

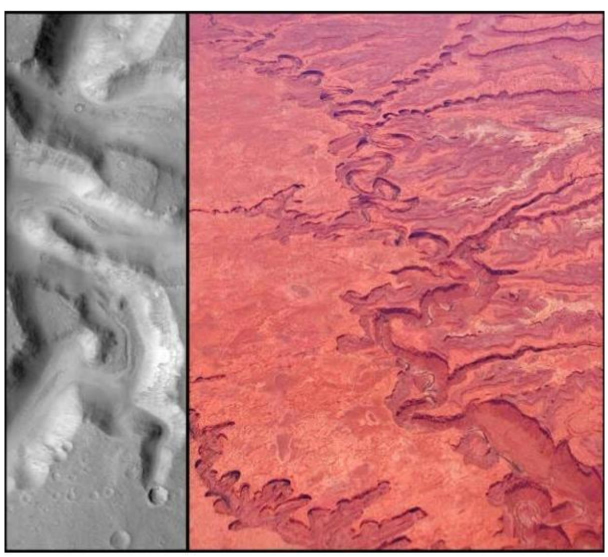
The grandeur of the southwest, however, is not just in its color but also in the gigantic forms that every year draw visitors from around the world. The blocky monoliths we see in canyon country are made mostly of great slabs of sandstone and limestone. Each layer reveals a moment in the history of this place; each layer tells the story of alternating seas, and seashores, dune fields and alluvial fans. Over millions of years nearby mountain ranges have risen and fallen, and new ones have taken their place. Rivers, rain, wind and ice broke those now forgotten mountains down and washed their remains downhill to west and east covering this region after the seas dried up.

Each epoch of erosion left its sand, silt, salt, mud and pebbles. New erosion buries these and, over time, lithofies the sediments (cementing them with pressure and heat) to form solid rock like sandstone, siltstone, mudstone, and shale.

Visible high in the wall of the Grand Canyon is the great pale band of the Coconino Sandstone. Through its face run great swooping bands that cross back and forth across one another. These are the fossilized remains of enormous sand dune fields: an ancient Sahara covering the southwest before the more recent seas appeared. Millennia of dry, shifting, sand dunes slowly drifting across the endless miles are recorded in the Coconino's sweeping, crisscrossing bands.

Erosion and time eventually buried these layer stacks, while tectonics (the stretching, pulling, cracking and shifting of a planet's crust) subsequently raised them far above sea level. Later, rain water and snow-melt, washing down to the sea, revealed the layers once more in newly formed cliff walls.

The entire Colorado Plateau is undergoing this process of erosion right now. As the North American plate slides over the Pacific Plate, this part of the crust has been lifted a mile up into the sky. We know it was once at sea level because of the fossilized remains of sea shells littering several of the rock layers. Today the south and north rims sit at an elevation of over seven thousand feet above the sea and water that flows across the surface works hard to find a way down to it. The Colorado river has spent millions of years cutting through this rock, washing away weak layers, while harder rock above collapses without support. The result is a mile deep marvel of nature with alternating terraces and walls.



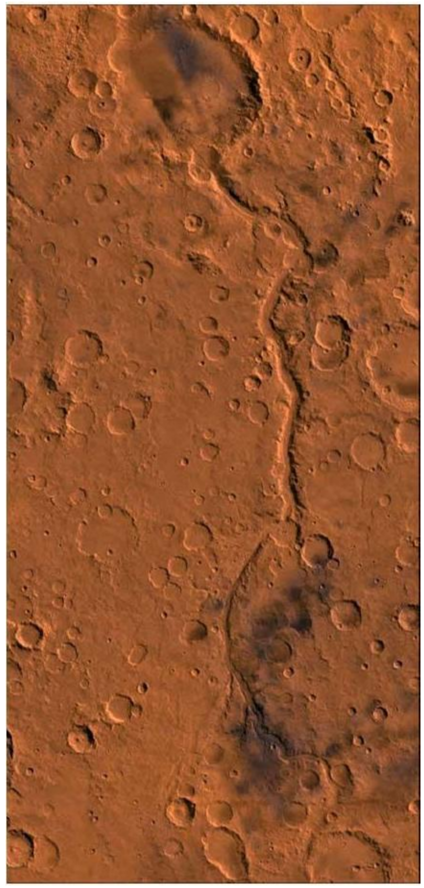
Channels on Mars (left), Earth (right).

The beauty and grandeur of the parks and monuments of the Grand Canyon **region is a testament to our active planet's past. If the history of the southwest had** been monotonous and unchanging, then there would be no differing layers, and the landscape we see would be far less varied and beautiful. Thus the majesty **of the** southwest is due to **fluctuations in its past, and for much of that time, up to and including the present, it is a** past **heavily** influenced by water.

Does Mars have a similar past?

To learn about the water history of **Mars is the primary mission of the two rovers** NASA sent to **Mars in 2003. They** were designed to explore two **different places** where **orbital images said water may once have been. From the Martian surface, these rovers,** Spirit and Opportunity, would examine the physical and chemical properties of the rocks. **Only from the rocks themselves** would we read, at long last, the history of Mars.

The two landing spots for the rovers, which were expected to last for 90 sols (a sol is one **Martian day)** and drive no more than maybe a kilometer, **were chosen specifically for their likelihood to have once had water. Spirit would go to Gusev Crater,** an enormous impact basin with a flat crater floor, 100 miles across. From orbit, it has **what appears to be a river canyon flowing into it, raising the possibility that Gusev may once have been a lake. Picture the Colorado River flowing through the Grand Canyon and emptying** into Lake Mead. Perhaps in the bottom of Gusev Crater would be the **telltale signs of sedimentary rocks, sandstones and siltstones, or at the very least the** chemical signs of rocks awash in water.



Gusev Crater on Mars

Opportunity was sent to the opposite side of the planet to explore a broad flat expanse called Meridiani Planum. From orbit, infrared observations detected the chemical signature of hematite, a dark grey iron mineral, that on Earth is usually formed in the presence of water (although sometimes through volcanism). Together, the two rovers were sent to places that scientists suspect should have once been awash in water — one on the basis of the shape of the landscape, the other on the basis of its chemical signature.

Spirit landed first in January 2004. The first image I remember seeing on the television that night was a tiny thumbnail sent back by Spirit of the sundial I helped work on. Whatever else I may do in life, a small part of me will now forever be on Mars.

In the weeks that followed, Spirit trundled about the hard-packed russet sand and scraped at the nearby rocks littering the surface. It analyzed their color and composition, photographed them in visible and infrared light, peered at them microscopically, and in the end determined that everything in its immediate area was volcanic basalt.

There wasn't a sign of water anywhere to be found.

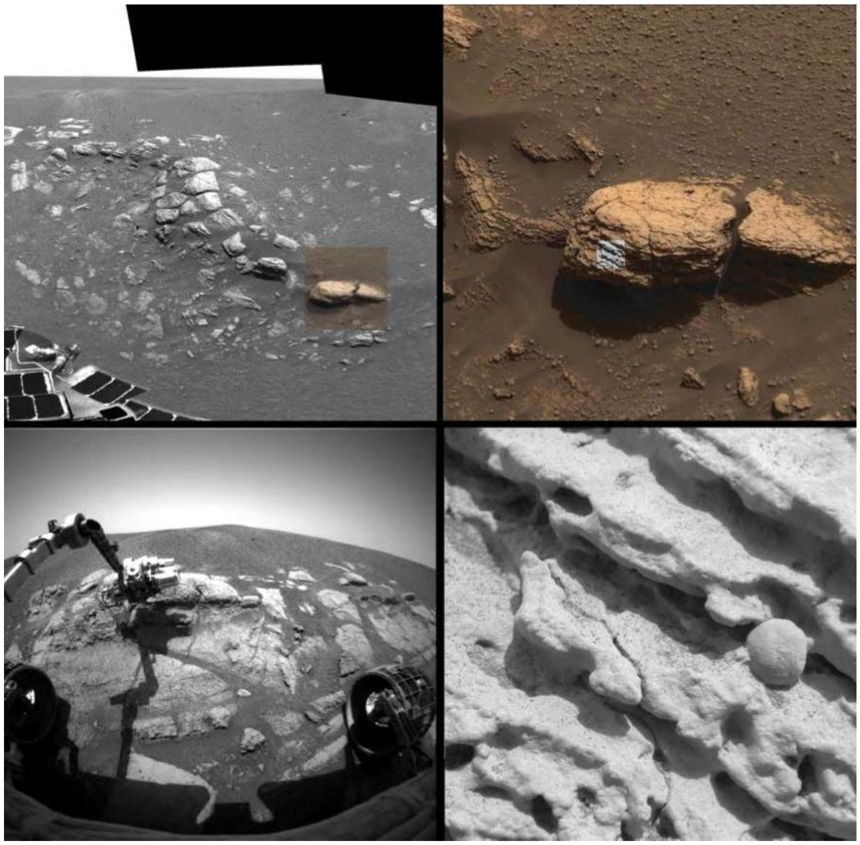
Meanwhile, on the other side of Mars, Opportunity's first images showed it to be inside a shallow crater only 65 ft across and less than 6 feet deep in the middle of a vast parking-lot of an empty plain. But there in the rim of the crater were the first bedrocks ever seen on Mars.

Bedrock, just like the walls of the Grand Canyon, tells you the history of where you are. It tells you exactly what the conditions were under which it was formed and by looking at what sits on top of what, it tells you the order in which it happened and how long it lasted relative to what came before or after. Bedrocks are novels to be read, whereas the loose rocks that littered the surface of every other previous Martian landing site were merely random pages scattered about from unknown manuscripts.

From the very first images of the bedrock it was also clear that the outcrop was layered. Two processes tend to lay down layers, volcanoes, and water. These are the same two processes that give rise to hematite on Earth and which process had been at work on the plains of Meridiani was exactly what Opportunity had come to determine.

Everywhere the rover's cameras looked, inside and outside the crater, tiny grey spheres the size of small marbles littered the surface. The landscape was covered with millions of them, and soon the science team labeled them "blueberries" because of their color relative to the ever-present red of the Martian countryside. Their source appeared to

be the layers in the rock wall, where the cameras could see signs of blueberries still imbedded. Over the millennia, the constant wind and sand appears to erode the layers, causing the relatively harder berries to pop out and roll across the surface.

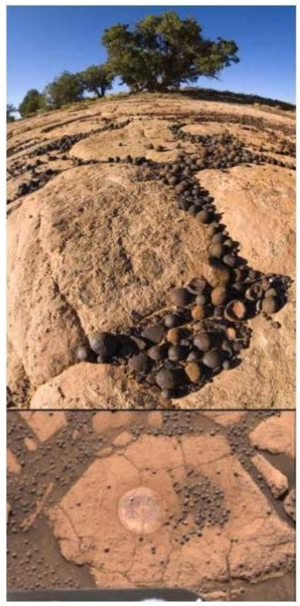


Bedrock, layers, and blueberries on Mars

Using a smaller version of the infrared camera that first detected hematite from orbit, the Opportunity team found that wherever there were blueberries there was the chemical signature of hematite, and where the blueberries were scarce, the hematite was not to be found. This relationship was confirmed when the rover team managed to get a spectrum of a small pile of berries, gathered in a depression, playfully called the "berry bowl." The tiny blue spheres were the hematite they'd been looking for.

Back on Earth, Marjorie Chan, a geologist at the University of Utah, saw pictures of the Martian blueberries and told herself, "I know what those are; there's been liquid

water there." Chan and her collaborators had just written a scientific paper describing the origin of strange iron spheres, informally called Moqui Marbles, found littering the surfaces of a number of outcroppings of Navajo Sandstone around southern Utah and Northern Arizona. In these areas, the normally iron red sandstone has been bleached nearly white of its iron. Where the sandstone is bleached, that's where you find the marbles, some still embedded in the rock layers.



Hematite concretions on Mars Earth (top), Mars (bottom).

Because Navajo sandstone, like the Coconino, began as dry sand dunes, it is relatively porous compared to denser sedimentary layers. Groundwater easily seeps through the gaps between the sand grains and so the Navajo layer acts as a subterranean plumbing system for regions where it's found.

According to Chan, the colors we see in red rock country occur because of iron-oxide that forms around individual grains of sand that make up the sandstone. As groundwater moves through the more porous Navajo sandstone, buried hydrocarbons (the oil and gas in the ground that makes this region so enticing for exploration companies)

dissolve the iron and carry it along in the water. As the sandstone loses its iron, the sandstone bleaches white.

When the iron-rich water encounters oxygen-rich groundwater of differing chemistry, the iron precipitates out of the solution. Slowly, these solid iron minerals bind together grains of sand and form tiny spheres called concretions.

One such iron mineral that does this is hematite.

With time, the hematite spheres grow until either the water movement stops, or the iron supply ceases. Eventually, when this area is raised by tectonic forces, the sandstone weathers away around the harder iron sphere. When it does, the marble drops out and rolls across the surface of Utah just like the blueberries on the planes of Meridiani. While the exact chemistry is a little different on Mars (no one expects to find oil reserves there) the result is the same.

But as with Lowell a hundred years ago, even the best scientists can be fooled by what they want to find. This is a possibility that scientists struggle with whenever they discover something new or something long hoped for. For the members of the Mars Rover team, they were going to do everything in their power to question their own conclusions, until there were no more viable alternatives to what they were seeing.

Over Opportunity's first 26 sots on Mars, numerous lines of independent experiment and imagery all flowed together into what emerged as a single unifying history of water.

First there is the fine rock layering not unlike anything you or I might find in the sandstone layers of the southwest. Within the layers are the hematite spheres, looking exactly as concretions should. In addition, the layering itself traces out tiny ripples in

exactly the right shape and pattern as if the layers of which the rock were made were laid **down by water waving and lapping across its surface.**

The rock layers themselves are composed of salts, just as if shallow briny lakes or seas had washed across the surface and then dried on a warm Martian day. Different layers were composed of different types of salt and in different concentrations, just as one would expect in a pond where the more water that evaporated the more salt would be left behind in the liquid that remained. Look west to the Great Salt Lake and the process is at work on Earth today.

Chemical analysis by one of the rover instruments revealed that one of the salts making up the Martian outcrop is a mineral called jarosite. It's not a common mineral on Earth, but it's one that has actual water within its crystal structure. So not only does the presence of salt speak of water's once distant presence, but one of the types of salt present still contains traces of water itself.

Meanwhile, all over the surface of the bedrock layers are tiny indentations or tabular-shaped pits. To all appearances they look like places where crystals grew, pushed aside or replaced the material that was there, and then dissolved or weathered away. On Earth, gypsum salts form little crystals like this as minerals precipitate out of rock awash in water. In time, as conditions change, the crystals weather away and all that's left are their little empty molds. These features are called vugs and you can see them in some of the layers of the Grand Canyon.

In his book, Roving Mars, team leader Steve Squyers (my old professor at Cornell) described the process of discovery this way: "Ever since we landed," he wrote, "I've been resisting the idea that there was water here at Meridiani. Maybe I just want to

be very, very certain before declaring victory." But, after the layers, and blueberries, and ripples, salts, jarosite, and vugs, after all these separate lines of enquiry,

> It's the preponderance of the evidence.... It's been fascinating to watch the whole team as these clues have been revealed to us, sol by sol over the past few weeks, like some kind of weird Martian mystery novel. Each of us has come to this remarkable experience with our own background, with our own set of prejudices. And each of us has reacted to the mounting evidence for water here differently. Some people leapt joyfully off the cliff when we got our first hint of the outcrop's composition.... Others still aren't convinced yet.... But today did it for me. I simply can't see how you can make rock like this without a lot of water being involved.... There's no doubt in my mind now that some of these rocks were laid down, long ago, in liquid water.

In the end, if Squyres and his team are right, Mars really once was warmer and wetter, with salt water lakes or seas rippling and retreating across the red Martian landscape just as it did where I stand here in Arizona. I look around me at the landscape of the country I love so much and I wonder, as similar as these landscapes may be today, was there a time when the comparison was even closer? Was there a time I when the sky was blue? When the streams did run? When the grass was green and the red planet wasn't nearly so red? And even with all we now know, might we still be wrong about Mars?

My red rock panorama of the imagination on Mars.

In November 2011 NASA launched the next generation of rover to investigate the chemistry of rocks that we now know once existed in water. On board that rover is another sundial. just like we included on Spirit and Opportunity. Wrapped around the side of the sundial is a message to future explorers that addresses this question of how much do we now know to be true that may not be true at all. It says:

> For millennia Mars has stimulated our imaginations. First we saw Mars as a wandering red star, a bringer of war from the abode of the gods. In the recent centuries, the planet's changing appearance in telescopes caused us to think that Mars had a climate like the Earth's. Our first space age views revealed only a cratered, Moon-like world but later missions showed that Mars once had abundant liquid water. Through it all, we have wondered: Has there been life on Mars? To those taking the next steps to find out, we wish a safe journey and the joy of discovery.

The one thing science teaches us over the centuries is the one sure way to never be right is to never risk being wrong.

Like Percival Lowell, John Wesley Powell, and everyone else who has ever been drawn to the stark beauty of the American southwest, we are following the water where it leads us on this new planet, reading the history it reveals, and wondering what life may have been here before us.

And like all sundials, the one on this new rover, carries a motto. Its motto is our motto: To Mars. To explore.

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Biography of the author: Dr. Tyler Nordgren is an astronomer at the University of Redlands. In 1997 he received his PhD in astronomy from Cornell University. From 1999-2008 he worked with NASA scientists converting the Mars rover camera calibration targets into working sundials. From 2007-2012 he has worked with the National Park Service to promote astronomy education in the parks.