Chapter 12

Life on Mars

Mars on a cosmic scale is close. It is an obvious place to search for life. Information comes in uninvited very few days when a Mars rock falls from the sky. Robots tolerate its surface environment. Much of the scientific work on Mars has been a search for water and life, both past and present. I had various bit parts that allowed me to watch the operation of science at center stage.

Until the middle 1900s, the populace held out hope and fear that intelligent beings lived there. The idiom of the Martian as an intelligent but uninformed individual reflects the benign side of this attitude. The first space photos of Mars brought sobriety. The surface looked more like the Moon than the Earth. The air is thin, with the pressure 0.6% of that at the Earth's surface. Subsequent photos in the Viking project of the 1970s showed what looks like ancient watercourses. The early planet was once more clement.

The Viking landers bought brought brief optimism followed by deep pessimism. The biologists designed the life detection experiments with terrestrial organisms in mind. The probes added water with edible organic matter to the Martian soil. Carbon dioxide, the expected product of reaction of organic matter with oxygen by microbes, reached the detector.

Further analysis showed that the soil contained peroxides that abiotically reacted with the culture fluid. Basically, photolysis by UV light in the Martian atmosphere splits H_2O into hydrogen which escapes and atomic oxygen most of which stays around. A single oxygen atom is very reactive. It can attach to a water molecule to form hydrogen peroxide H_2O_2. Ultraviolet light striking ice has the same effect. Hydrogen peroxide attaches to form weakly bound compounds in the soil. The water added by the probe formed a solution with various peroxide molecules.

Hydrogen peroxide is toxic to terrestrial organisms. You may have used it as an antiseptic. You may have used it to make your hair blonde. Most of the Viking biologists concluded that if you wanted to kill microbes send them to the surface of Mars. Subsequent understanding of ecology has gnawed away at this conclusion. I begin with the first big bite.

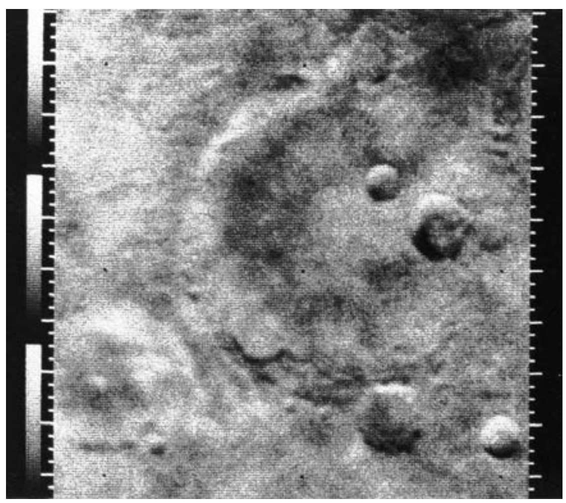


Figure 1: Mariner 4 imageJPL-7875A shows cratered terrain. The width of the photo is about 300 km.

Mars and magnets

The idea of life on Mars still excites. Kevin Zahnle and I were peaceably preparing a journal paper that early Mars was a safer place for microbes than the early Earth. There was no need for haste because the next Mars mission was years away. While I was driving to a weekend in the Sierras with my family, the radio blared that NASA scientists had found life in a rock from Mars. I knew it had to be ALH-84001. ("ALH" stands for Allan Hills in Antarctica where the rock was found. It is relatively easy to find dark meteorites in places where the ice comes to the surface and evaporates. "84" stands for the December 1984-January 1985 field season when it was found. "001" means it was the first one of that year's collection from the Allan Hills catalogued upon return to the Johnson NASA center.) This rock is 4.5 billion years old. It looks so much like an Earth rock that the scientists had to argue with the technicians to bag it. It contains cracks filled with mineral deposits from circulating low-temperature water. This environment teems with life on the Earth.

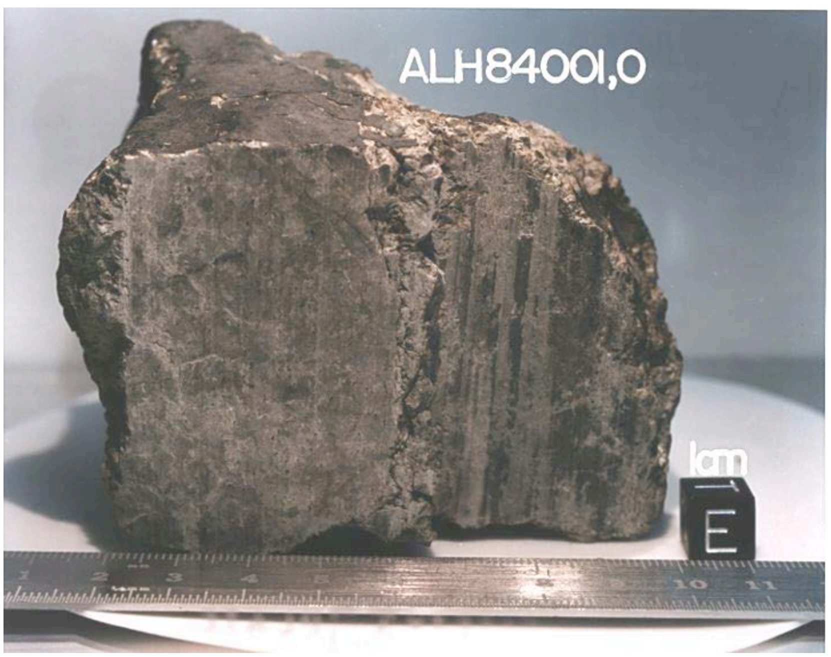


Figure 2: Mars rock ALH 84001 is about 4.5 billion years old. It resembles terrestrial rocks. Scientists study possible fossils within veins left by ancient water circulating through the rock. http://rsd.gsfc.nasa.gov/marslife/photos.htm

The press focused on tiny worm-shaped structures in the rock. These features are smaller than extant terrestrial organisms. This bothered biologists in that there is a minimum size for microbes resulting from the fact that there are a finite number of atoms in each cell. Paleontologists were justifiably wary. They had been burned by interesting-looking pseudo-fossil structures in ancient Earth rocks.

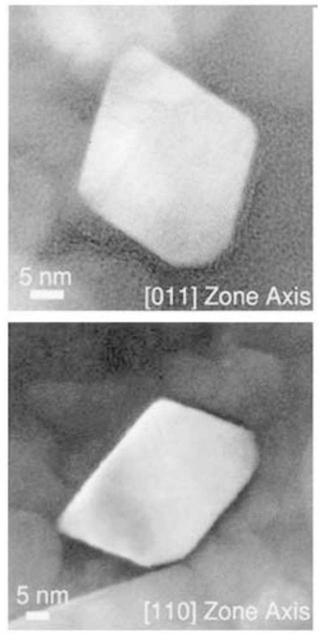


Figure 3: Kathie Thomas-Keprta imaged magnetite grains in the Mars rock ALH 84001. These 3.9-billion-year-old grains resemble modern biological magnetite and magnetite fossils on the Earth. This is evidence that live existed on Mars as physics determines the optimal shape of biological magnetite. Figure 4 in Applied and Environmental Microbiology, Aug. 2002, p. 3663–3672 Vol. 68, No. 8, 0099-2240/02/$04.00_0 DOI: 10.1128/AEM.68.8.3663–3672.2002

Scientific attention gravitated toward tiny (less than 1 millionth of a meter across) magnetite grains in the rocks (Figure 3). Terrestrial organisms use such grains for magnetic compasses. We have them in our brains, but they have not been shown to form a useful sense. Maybe they help with balance. The birds and the bees use them to find their way around. Carrier pigeons get lost in places where the local magnetic field varies erratically.

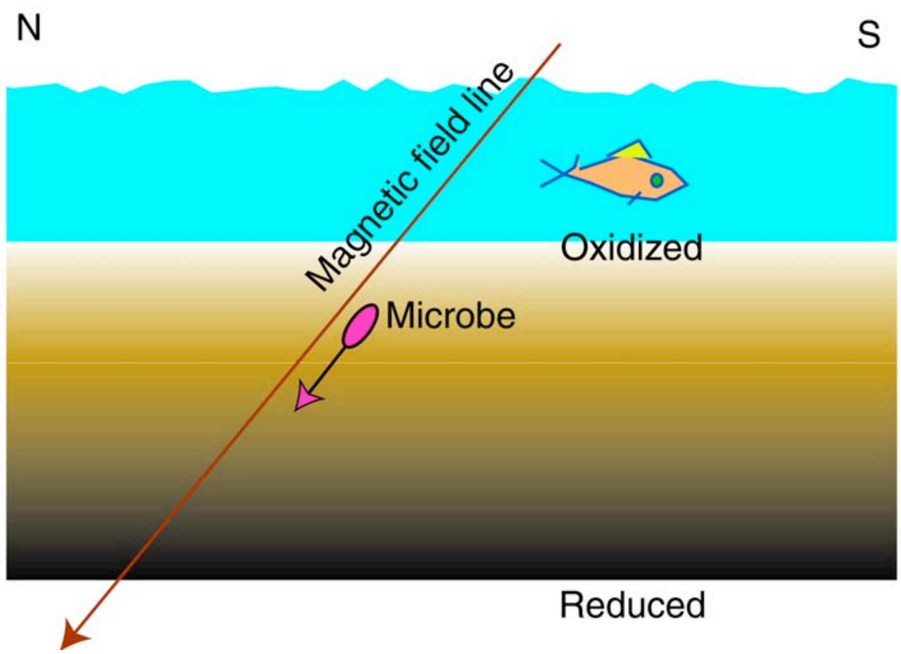


Figure 4: Magnetic microbes follow magnetic field lines to find conditions to their liking. Here the magnetic lines are down and north in the Northern Hemisphere. Typically the sediments are oxidizing at the surface and reducing at depth. This microbe moves along a field line to find more reducing conditions at depth. It is inefficient to move downward at an angle, but this is a lot better than wandering around lost. This adaptation is useful wherever gradients exist between oxidizing and reducing environments. This includes sediments and water bodies like the Black Sea. This situation exists now in the subsurface of Mars. The surface is strongly oxidized while the subsurface is reduced.

Microbes use tiny magnetite grains them to find up and down (Figure 4). In the Northern Hemisphere, the magnetic field (with the standard sign convention) points north and down. We can measure the downward component with equipment dating from William Gilbert's work around 1600. In the Southern Hemisphere, the field points north and up. At the magnetic equator it is horizontal. The force of gravity on a microbe is too small to aid it in finding up and down. The force on the magnetite grain from the Earth's magnetic field is much larger than the gravitational force. The organism finds up and down using the magnetic field. The field is not vertical except near the poles but it is more efficient for the microbe to go up and down at an angle than it is for it to wander aimlessly.

There is an optimum size and shape for a magnetite grain to function as a compass. It needs to be elongate in a particular crystallographic direction. Magnetite does not grow this way on its own. It, like salt and garnet, tends to grow equidimensionally. Magnetic microbes have highly evolved mechanisms to grow the grains that they "want."

Careful comparison of the magnetite in the Mars rock and magnetite from terrestrial microbes by a group led by Joe Kirshvink showed that the Mars magnetite resembles that from terrestrial organisms. This is important because the need for microbes to move up and down occurs on Mars. As on the Earth, the surface is more oxidized on average than the subsurface. The optimal shape for the grains is physics. Evolution will converge towards it.

The magnetite in many living microbes comes in chains of grains, like a line of bar magnets. Reliable detection of such chains in the Mars rock would elevate the potential biosignature to a fossil of past Martian life. To date, scientists have found no convincing chains in the Mars rock.

In all science, the level of evidence to establish a major claim, that life existed on Mars, is higher than that for a routine claim. Less evidence suffices to trigger further work. This is generally true in ordinary affairs. For example, you would not have much trouble convincing people that you saw a pigeon in the park. You would have a lot of difficulty if you claimed to see a pterodactyl, but you might get someone to come with a good camera or a net. There is nothing illogical or mystical about life on Mars. It is perfectly consistent with what we know. We just want to be sure before we say we are. The level of evidence for really outlandish claims is much higher.

Wet Mars

Robotic probes provide photographic coverage of the surface of Mars. In fact, we have much better information than is available for the ocean basins on the Earth. There are numerous now dry features that resemble terrestrial stream courses. Planetary scientists date them and the rest of the surface of Mars using space photos. The methods are basically that used to obtain relative ages on the Moon. On a local scale Steno's laws work. Young craters and lava flows cover older ones (Figure 1). On a regional scale, highly cratered regions are old. Drainage networks cut the oldest regions on Mars. Craters cut the channels in places. No water has flowed for billions of years.

Given the current dryness of the surface, some scientists have questioned whether water was really the erosive fluid. Very hot and fluid lava and liquid carbon dioxide have come up has alternatives. The Mars rover programs checked out key localities that could be safely reached. They found evidence of water an ancient Mars. The also found that water made local and brief appearances throughout the later part of the planet's history.

Figure 5: Big Rock Creek in the San Gabriel Mountains of southern California. These angular to slightly rounded rocks have been transported less than a few kilometers from their source. A geologist can determine what rocks are exposed in the drainage by examining the boulders. The larger rocks are 0.5-meter diameter. The trickling stream is now unable to transport these large rocks. The rocks moved last in a large flood the previous winter. Photo by the author.

Pathfinder. Rivers carry rocks downstream (Figure 5). You can learn what is in the drainage by looking at the rocks at the river mouth. Gold miners used this method extensively. They panned and determined which fork of a stream was carrying gold and then followed the flakes upstream to their source.

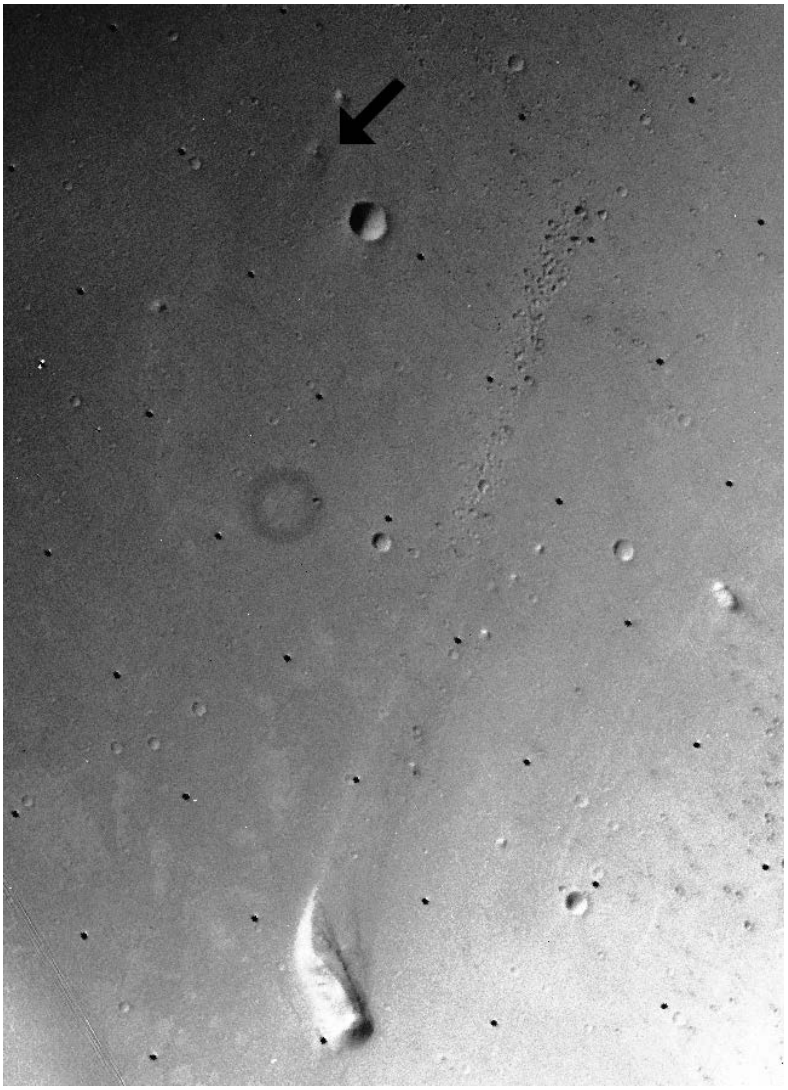


Figure 6: The Pathfinder rover landed in the middle of a vast ancient flood plain (arrow near top of photo). The crater near the landing site is 1.5 km in diameter. The feature at the base of the photo was once an island in the flooded landscape. Wind erosion has modified it extensively. NASA Mars photo marspath_landing_site_ar.jpg.

The Pathfinder rover mission to Mars applied this strategy by landing in a vast flood plain (Figure 6). The deposits formed during catastrophic floods, perhaps from the failure of ice dams. They left the surface strewn with rocks (Figure 7). Pathfinder could examine rocks from a several hundred kilometer wide area on Mars without going far a field.

Figure 7: Angular rocks at the Pathfinder site on Mars. They were transported hundreds of kilometers from their sources in a great flood over a billion years ago. Wind erosion beveled some of the exposed faces. Dust covers most of the surface. NASA Mars photo marspath_81093.jpg.

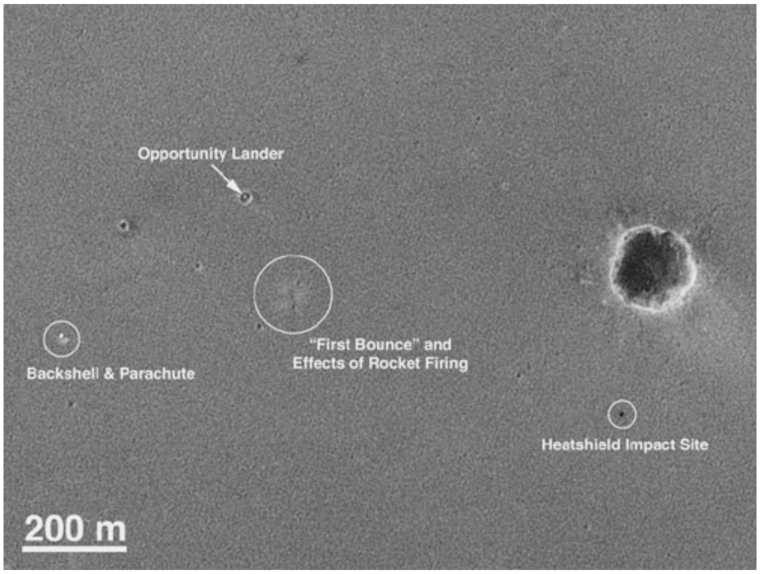
The rover needed to scratch through the dust that covers Mars to analyze the chemistry of the rocks. As expected from Martian meteorites, many of the rocks are basalt, the black rock that erupts on Hawaii and at mid-oceanic ridges on the Earth. Somewhat more surprisingly, there was andesite, the rock, which erupts at island arcs (See Chapter 8). On the Earth, water is required to make andesite. The subducting slab carries hydrous oceanic crust down into the mantle. The crust dehydrates and it water ascends into the overlying mantle. The mantle partially melts at a depth of around 100 km. The magma ascends into the crust of the arc. It partially freezes leaving andesite, which erupts often explosively, like at Mount St. Helens.

Does this imply that there were once plate tectonics on Mars? Scientists would like more information. The rover could not do a complete chemical analysis as would be done in the laboratory on the Earth. Petrologists know that some rocks similar to andesite do not require subduction. Basalt may assimilate hydrated material at crustal depths. Even basalt weathered by water may mimic andesite. In any case, plausible methods of getting andesite-like composition require water and lots of it. The flood plain required lots of water over a brief time.

More rovers, orbiters, and surface chemistry on Mars. Subsequent rovers sought sites where there might be direct evidence of long-lived water bodies and maybe life. By then orbiters had provided preliminary chemical analyses of much of the surface.

The *Opportunity* rover landed in Meridiani Planum. Orbital images had directed crystalline "grey" hematite. This mineral has the same composition as red rust, ferric iron Fe_2O_3. On the Earth, it occurs within sedimentary iron formation, which formed when the deep ocean was anoxic and the shallow ocean oxic (between 2.5 and 1.8 billion years ago). These deposits were biologically moderated on the Earth with photosynthetic bacteria making the ferric iron. Burial within the Earth aided the conversion of red rust to grey hematite crystals.

Scientists did not have a good idea how the Martian hematite formed, but the terrestrial analogs were intriguing. Perhaps there were ancient marine deposits. Maybe these deposits had been deeply buried and then exhumed. The real source of the hematite surprised everyone. I digress to put this discovery into context.



(02_overview_labels-B016R1_br.jpg) *Opportunity* bounced across the surface of Mars ending up in the one small crater near the landing site. In analogy to golf, the scientists quickly named the site Eagle crater. The walls of the crater exposed beds of sedimentary rocks (Figure 8). The rover moved to scan the pay dirt.

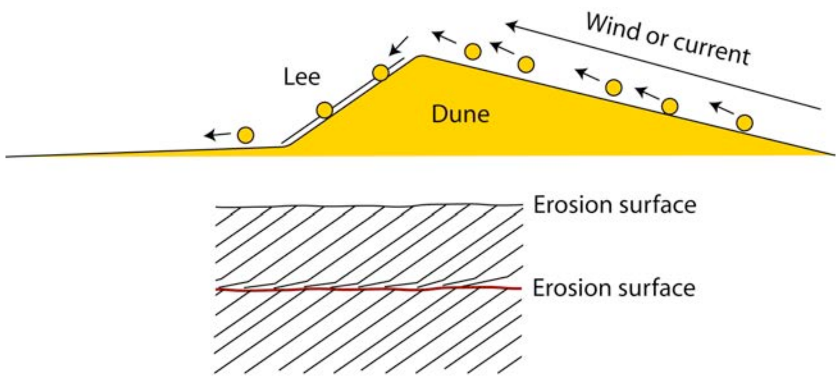


Figure 8: Cross bedding on the Earth forms when the wind or currents and waves in water transport loose material. A moving dune is easiest to visualize. The wind drives grains up the windward slope. The grains fall down the slip face on the lee side. The accumulate their and in front of the dune. The dune moves downwind forming a series of beds on the lee slope. Erosion frequently bevels the surface. Viewed in outcrop, series of beds formed in front of moving dunes occur between more flat erosion surfaces.

Close examination of the outcrop relieved cross bedding (Figure 8). The type of cross beds in the outcrop formed by oscillating waves on a lake shore. There was once standing open water on Mars. Later the rover found outcropping beds formed by moving dunes.

The chemical composition of the rock relieved further evidence of open water. Much of the rock is composed of sulfates including calcium sulfate $CaSO_4$ and the uncommon (on the Earth) mineral jarosite $KFe_3(SO_4)_2(OH)_6$ (Figure 8). Scientists had expected the former. Previous analyses of Martian soil had indicated the presence of sulfur. This element as sulfide is common within igneous rocks. Sulfate forms whenever the rocks weather in the presence of oxygen. Calcium is a common element in rocks that is leached during weathering. Calcium sulfate $CaSO_4$ precipitates when seawater or episodic lake water evaporates.

Jarosite forms in much more restricted conditions. Its ferric iron component is soluble in acid water. Jarosite forms in semi-arid seasonal climates on the Earth. Iron sulfide FeS minerals weather during the wet season. The iron oxidizes to ferric iron Fe_2O_3 and the sulfide oxidizes to sulfuric acid H_2SO_4. The acidic solution contains ferric iron and some potassium (K in the jarosite formula). Jarosite precipitates when the water evaporates.

Evaporation is no problem on the dry surface of Mars. The rest of the process places constraints on the ancient Martian environment. Common igneous rocks on the surface of Mars rocks like basalt contain over 100 times more calcium CaO and magnesium oxide MgO components than they contain iron sulfide. Slow weathering produces calcium sulfate $CaSO_4$ and magnesium sulfate $MgSO_4$ in solution, not sulfuric acid and jarosite. Having oxygen in the air speeds the oxidation of iron sulfide. Intriguingly, so do microbes on the Earth.

Figure 8: The Mars rover found outcrops of rocks. Chemical analyses show that these rocks accumulated in acidic water. There is indication of wave activity from close-up photos. The cliff is less than half a meter high. JPL photo 21-AK-05-camel-A074R1_br.jpg

The grey hematite turned out to be small spheres called “blueberries” because of their size and shape and hue against the red surface of Mars (Figure 9). The blueberries precipitated within the sulfate-rich sedimentary rocks after they were deposited. Circulating water replaced small spherical parts of the rock with hematite. On the Earth, such features called concretions sometimes form around small flecks of buried organic matter. The rover was not planned with this in mind and did not have equipment to look at that scale.

The absence of obvious organic matter at Meridiani Planum is perhaps ironically a weak biosignature. Microbes in similar environments on the Earth eat the organic matter by reacting it with the abundant ferric iron and sulfate to form carbon dioxide, ferrous iron, and sulfide.

Figure 9: Blueberry strewn surface on Mars. They are most visible near the center of the photo. The blueberries are not easily moved by the wind. They form a surface deposit as they weather out of the rock. NASA photo _xpe_pubeng_approved_032304_color_berry_bowl-B060R1_br.jpg

Overall water had at least four roles at Meridiani Planum: (1) Water circulating through the rock reacted to form ferric iron and sulfate. The water flowed into a lake. (2) The lake evaporated. Waves in the lake formed cross beds on a beach. (3) Water circulated through the sediments. It formed blueberries. It also dissolved out some crystals leaving crystal-shaped voids. (4) As elsewhere on Mars, water circulated through the ground. The water dissolved sulfate, salt NaCl, and bromine compounds. The water evaporated just below the surface. The rover operators discovered that they could scratch of the uppermost soil to reach the salt crust.

The second rover *Spirit* landed in Gusev crater. It was intended to search for ancient lake deposits. It did not find any, but did find rocks altered by following groundwater and salt deposits within the Martian soil. Geochemists have found such salt deposits and alteration within Martian meteorites. Radioactive age determinations indicate that these rocks are over 4 billion years old. They last saw liquid water over 100 million years ago. It would be impossible to find exposed rocks anywhere on the surface of the Earth that have not had liquid water in the last few thousand years. The third rover *Curiosity* did find ancient lake deposits as expected.

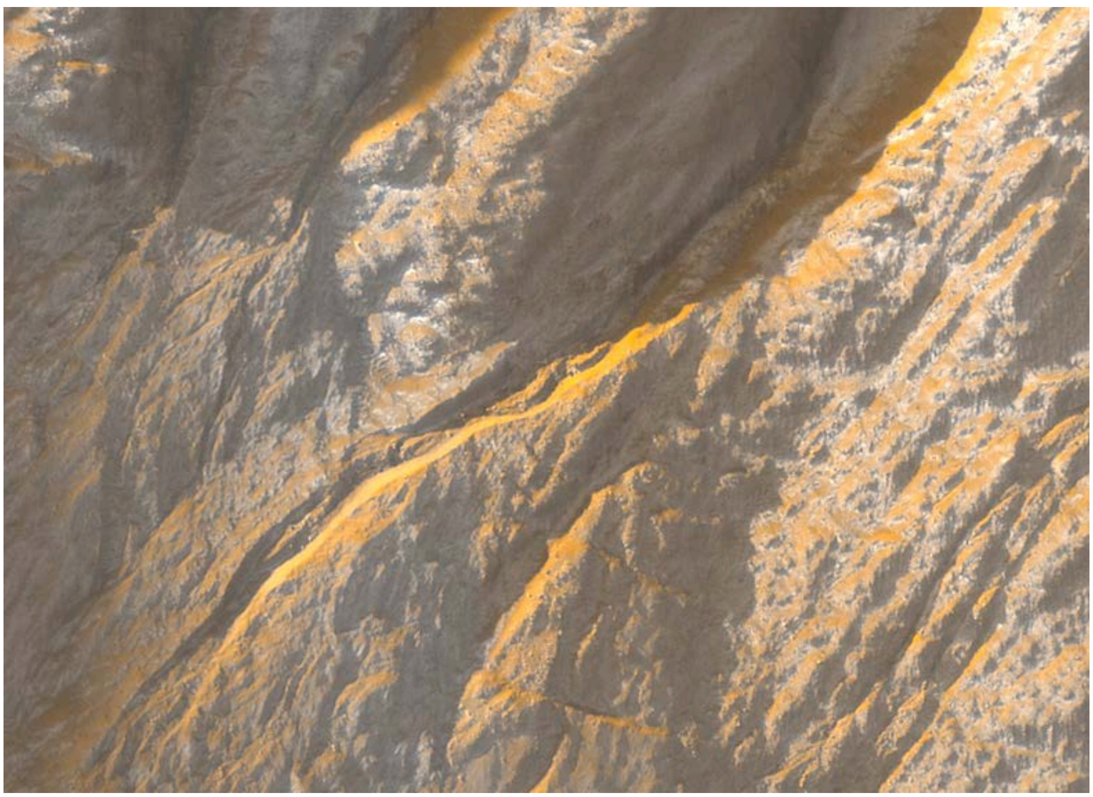


Figure 10: Recent gulley on Mars. The field of view is 200 meters across. The exposure resembles a steep plant-free canyon wall in a terrestrial desert. NASA photo D-Gully-highlight.jpg.

Recent surface activity. High-resolution photos from orbiters, like spy satellites, bought in detail from the Martian surface. Liquid water continues to make appearances on the Martian surface. Young (less than 1 million years old) gulleys exist particularly on steep slopes. They change seasonally indicating current escape of water.

Scientists do not yet understand these features. The mean annual temperature is well below freezing. Slowly flowing water would freeze in the pores. The arctic regions of the Earth give some analogy. Thermal springs with temperatures of a few degrees Celsius do exist. The water flows up faster than it can cool. On Mars, the water would evaporate and freeze. Ice damming the spring mouth episodically fails, unleashing small floods.

Freezing and thawing at depths of kilometers can also unleash floods. This process occurs in the arctic on the Earth but the scale is smaller. The physics are straightforward. The temperature within the Mars and the Earth increases with depth. During warm periods the base of the ground ice melts upward. During cold periods, the base of the ice freezes downward. The freezing front is often irregular and pockets of water get trapped within the ice. This water cannot get out through the impervious ice. Rather its pressure builds up as ice expands (by 10%) as it freezes. Eventually, the pressure exceeds the strength of the rock and the ice. The water breaks a crack to the surface. Water vents reducing the pressure. Sealing by ice and further freezing repeat the process. You may have seen ice rupture a bottle or can that you forgot in the freezer.

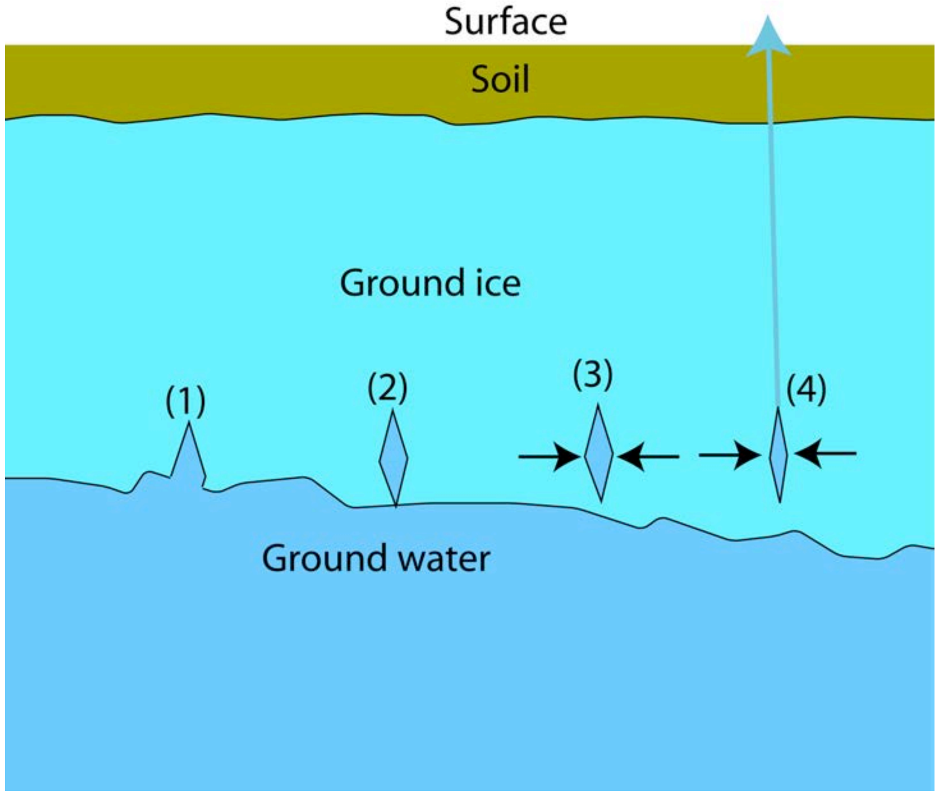


Figure 11: Sequence to vent deep ground water to surface. (1) Irregular freezing front penetrates into ground water. (2) ground water region surrounded by ice. (3) Further freezes of expansing ice squeezes pocket of water. (4) Pocket ruptures and crack ascends to surface forming spring.

On the Earth, the water often does not fully vent. Instead it ponds and freezes within shallow deformable soil. The surface domes up as more water ponds and freezes. Scientists use the Inuit word "pingo" for these common features.

The climate on Mars changes as the tilt of its axis and the distance from the Sun in the local summer vary. These variations modulate ice ages on the Earth. They are more intense on Mars. The ice front is now moving downward in many localities.

Interplanetary life transfer: If you don't like here it you can leave!

I heard forms of this statement during the Vietnam era protests from both sides. It indicated the level of frustration. It also indicated that America was still a democracy from which one could exit. Can microbes survive impacts by escaping the Earth or Mars? Have biota exchanged between the two worlds? At first, this seems to be insanity. An impact strong enough to blast a rock off a planet would surely sterilize it. Yet this is not the case, we may well have Martian ancestors.

Mars rocks. In the 1970s, it was a given that no rock could be blasted off a planet intact. There weren't thought to be any planetary meteorites even from the Moon. Careful search of collections in the early 1980s yielded both lunar and Martian meteorites (Figure 2). Scientists recognize the former because we have Moon rocks from Apollo and robotic Soviet missions. Mars rocks are recognized from tiny amounts of trapped atmospheric gas. The robotic Viking mission analyzed Mars air.

The big surprise is that ejection did not greatly shock the Mars rocks. The physics are simple. An impact sends a shock wave into Mars that emerges at the surface. There are no rocks to retard the shock wave so it accelerates to the surface to escape velocity, spalling off the uppermost rocks. It does not greatly shock the rocks it ejects. It is somewhat like swatting a fly. If you hit it against the wall (like the shock wave deep in Mars) you crush it, not accelerate it. If you hit it in the air, you accelerate it. You may do some damage but the opposite side of the fly from the swatter is intact. Experiments on living terrestrial microbe confirm that impacts are not good for them, but the conditions in shock ejection are not lethal.

Entry to the Earth's atmosphere is not particularly dangerous. Only the outer few millimeters of an incoming meteorite get hot. Heat does not have time to conduct far in the few seconds of reentry. For example, a worm farm survived the crash of the *Columbia*.

There has been plenty of opportunity for life to go back and forth between the Earth and Mars. A Mars rock falls on the Earth every few days. They look like Earth rocks so the first call is often to the police if one goes through a window. Early in the solar system the impact rate was 100 times higher. Trillions of Mars rocks have come to the Earth. Billions made the trip in a few thousand years, a reasonable time for microbes to survive.

Microbes disperse quite rapidly on the Earth. Free-living forms are global or very wide ranging occupying all suitable environments. This is true even for organisms that live in the subsurface. It is possible that Mars and the Earth were one biosphere early in the solar system. It is also possible that transfer occurred but was more limited.

Meteorites as a refuge: Lice. The first-grade parents are irate. They have had to repeatedly treat their kids for lice. Conspiracy advocates think the lice-killer manufactures have figured out it is more profitable to kill only 99% of the lice. Others blame the herbal medicine that some parents use. The rational suggest treating all the children at once. This idea does not catch on.

Planetary sterilization from impacts is like lice. It does no good to treat one child at a time if the other children still have them. It is much harder to sterilize solar systems if there is more than one habitable planet. There are many more small asteroids that can eject rocks than really large, dangerous ones. Dangerous impacts can even eject rocks that fall back to their home planet in a few thousands years when the climate has returned to clemency.

Looking at the genome. Do we see evidence for exchange in the genome of extant life? Maybe. A safe goldilocks zone exists in the subsurface of planets. The shallow regions are pleasant most of the time but get zapped by impacts. The deep regions are too hot all the time. The region in between stays safe. It is cooler and extends down to greater depths (by a factor of 2.5) on Mars compared to the Earth. The Bacteria and Archaea may represent the descendents of pioneer colonists from Mars that adapted to thermophile life on the Earth. Impacts on the Earth zapped their low-temperature relatives. The Eukarya's last common ancestor may not be thermophile. It may represent a late Mars colonist that never experienced a dangerous impact. If these ideas are correct, Archaea and Bacteria would have exchanged genes with each other before Eukarya got here.

Have I taken leave of my senses? No. Mars was open for life before the Earth. If life formed quickly there, it could have seeded the Earth before local biota evolved. Actually this hypothesis is more testable than life originating on the Earth. The Earth's rock record is gone. Exposed rocks on Mars predate the Earth as a habitable planet. In any case, we will know if the Mars and the Earth exchanged life. Sampling is just formidable logistics.

Toward the bottom line: Looking for life on Mars

How do we explore Mars for life? First, we keep astronauts home. The discovery of a live microbe would be one of the major discoveries of science. Even fossils would rank as a major discovery of the century. The work will deal with microscopic quantities unless we get very lucky. Why send astronauts and tons of contaminants at great expense? In the nine months that it takes the astronauts to get to Mars, their quarters will get dirty to the point of a homeless shelter. If the Shuttle and Space Station programs are any hint, they will bring along ant farms, adding vermin to filth.

Robotic sampling will have to take into account that life may have been exchanged between the Earth and Mars. Martian life may be related to terrestrial life. We cannot automatically call anything that looks biochemically like a terrestrial organism a contaminant. Conversely, we cannot depend exclusively on methods, like ribosomal RNA, that require the Martian organisms to be closely related to terrestrial ones.

As in most astrobiology, the exploration will follow the water. Robotic probes have already found water-laid sediments and stream channels. There are hints of local recent venting of water to the surface (Figure 10). The ancient environment was not that different from the Earth. The experience of biologists and geologists on the Earth is applicable.

Tectonics died and the Martian surface dried slowly over geological periods where evolution can act. Any remaining Martian life eeks out its existence. The Earth provides analogy. The subsurface of the Earth is inhabited and much of its life does not depend on photosynthesis. The Martian subsurface is not much different from the more stable areas on terrestrial continents. Drilling on Mars is difficult, but springs bring water and perhaps life to the surface. Ice may sequester the bounty where we can gather it.

The scientists will need to think some out of their terrestrial box. For example, the biota may well be adapted to the highly saline brines that actually melt. Unlike terrestrial halophile (salt-loving) microbes, the insides of Martian cells may be quite saline. They may find pure water to be a deadly poison. Conversely, microbes may eat hydrogen peroxide releasing molecular oxygen. There is bountiful energy available for a microbe with this talent, which is not outlandish. Complicated enzymes exist in terrestrial organisms including us for making hydrogen peroxide to rid the cell of unwanted organic compounds. Photosynthetic organisms have complex biochemistry that cleanses the cell of unwanted peroxide. However, there is no known terrestrial organism that uses peroxide to obtain energy.

Photosynthesis may have even occurred on early Mars when there was standing water and ice that partially melted in the summer. Snow algae teem in the latter environment on the Earth. The red color of the planet might even owe extinct to oxygen- or ferric iron-producing photosynthesis. Scientists have yet to locate water-laid sediments from this epoch.

What about quarantine? It is probably unnecessary for returned samples from the surface of Mars. We will take Herculean efforts anyway to keep them from being contaminated by terrestrial microbes. Mars rocks fall into the Earth every few days. Quarantine of surface rocks would do as much good as a medieval one on a ship where the rats had already swam to shore.

There are rational grounds for quarantining a viable Martian organism. If it is quite different than terrestrial organisms, on the other hand, it may be valuable in biotech. Any Martian organisms we get in the near future will be cold adapted to the near surface, where we can look. They will be easy to contain if they find room temperatures lethal.

Notes

For a discussion of the history of scientific and popular views of life on Mars, see "Decline and fall of the Martian empire," by Kevin Zahnle in *Nature*, July 12 2001 (volume 412, number 6843, pages 209-213). This work contains references to the debates between Percival Lowell and Alfred Wallace on Martian habitability.

You can get a measure of the importance that the public attaches to Mars with the procedures followed by NASA with the possible fossils in the Mars rock ALH-840001. NASA sent the technical paper to the White House for approval before it could be it released. However, the information leaked from the White House to the press in a confused form involving Pluto. Besieged by media inquiries, NASA hastily called a press conference. The Stanford scientists on the team and the Stanford press officers flew to Washington, D.C. on hours notice. I was to have been brought into the loop just before the press conference and could not be located. Frantic calls from the Stanford press office filled my answering machine while I was in the Sierras.

NASA has made an effort at openness with its Mars program. NASA provides easily accessible websites with logs of press releases and the latest information on active Mars missions, past missions, and missions in planning. They solicit input from the scientific community on landing sites.