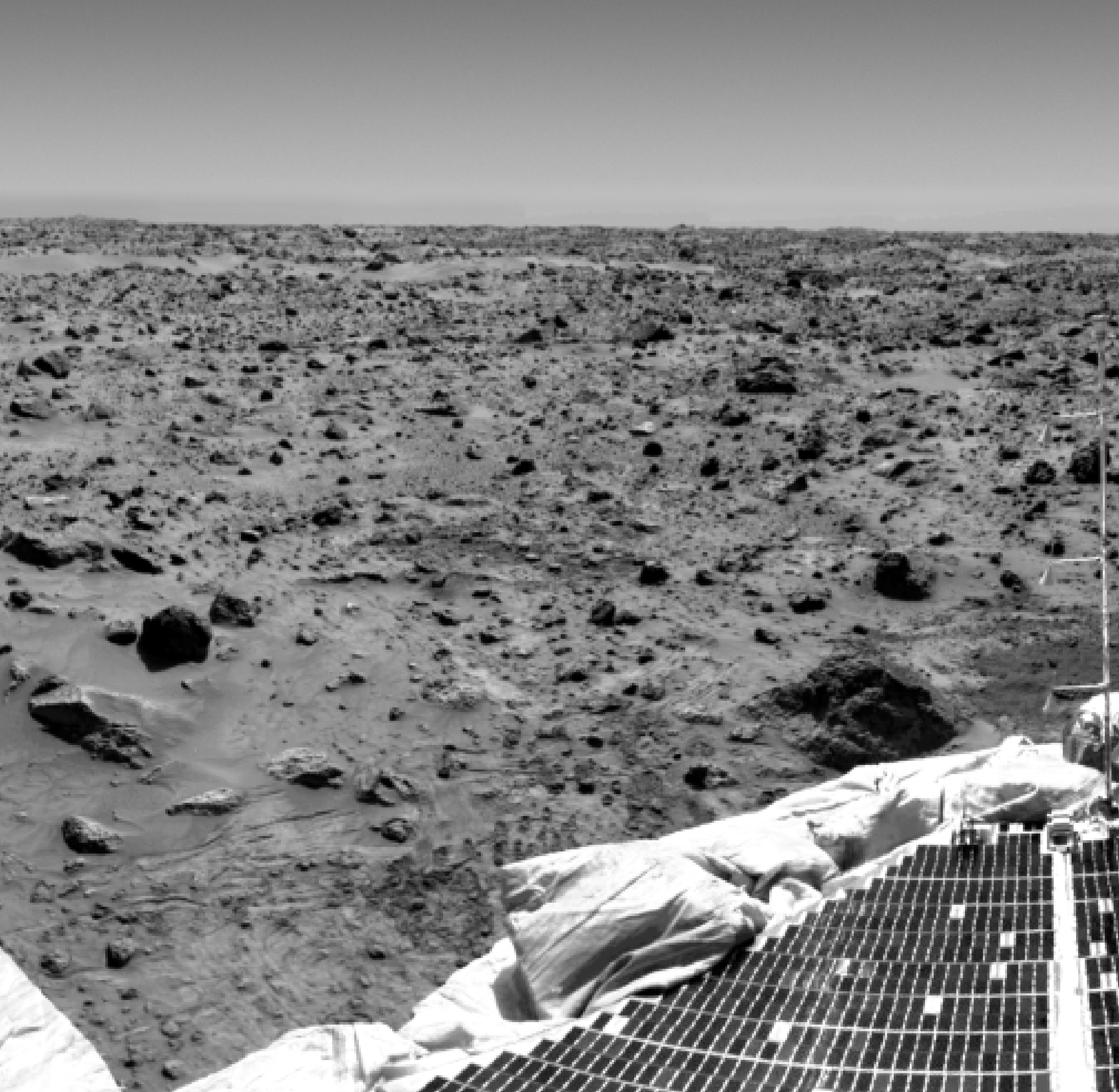
Reality provides us with
facts so romantic that imagination itself
could add nothing to them.

JULES VERNE (1828–1905)



MYSTERY

10

Is There Life Elsewhere in Our Solar System?

Science fiction writers once wrote epic stories of civilizations on Mars. Visions of a Martian civilization have long since faded, but today scientists are debating whether a meteorite holds fossil evidence of microbial life on Mars. In this mystery, we will discuss the prospects for finding life elsewhere in our solar system, with particular emphasis on the cases of Mars, Europa (a moon of Jupiter that is believed to have a subsurface ocean), and Titan (a moon of Saturn that is rich in organic compounds).

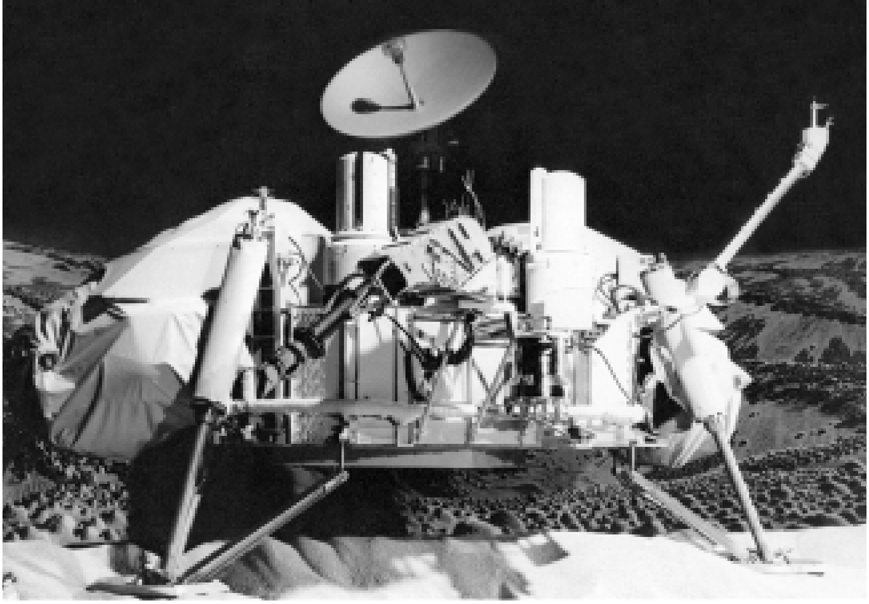
A century ago, belief that a civilization lived on Mars was so widespread that the term "Martian" became essentially synonymous with "alien." Although occasional speculation about life on Mars goes far back into history, the craze began in 1877, when Italian astronomer Giovanni Schiaparelli reported seeing linear features across the surface of Mars through his telescope. He named these features *canali,* the Italian word for "channels." English accounts mistranslated the term as "canals," and coming amidst the excitement surrounding the recent opening of the Suez Canal (in 1869), Schiaparelli's discovery soon inspired visions of artificial waterways built by a Martian civilization.

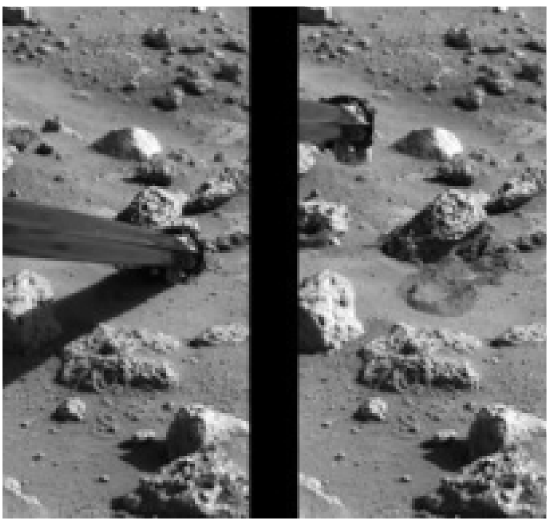
Schiaparelli himself remained skeptical of such claims, and it's not clear whether he even thought the *canali* contained water. He may simply have been following a long-standing tradition adopted for the Moon, where visible features were referred to as bodies of water. But his work caught the imagination of a young Harvard graduate named Percival Lowell.

Lowell came from a wealthy and distinguished New England family. His brother Abbott became president of Harvard and his sister Amy was the well-known poet. After a few years as a businessman and as a traveler in the Far East, Percival Lowell turned to astronomy. Impassioned by his belief in the Martian canals and enabled by his wealth, Lowell commissioned an observatory (the Lowell Observatory) in Flagstaff, Arizona. Upon its completion in 1894, he set about making regular observations of Mars. In 1895, he published detailed maps of the canals, as well as a book expounding not only his belief that they were constructed by a Martian civilization but also his conclusions about the nature of that civilization. Because Lowell had correctly deduced that Mars was generally arid and had icy polar caps, he imagined that the canals were built to carry water from the poles to thirsty cities nearer the equator. (He was incorrect in assuming the polar caps to be water ice; they are largely carbon dioxide ice.) From there it was a short step to imagine the Martians as an old civilization on a dying planet, and the global network of canals convinced Lowell that they were citizens of a single, global nation. Such ideas provided the "scientific" basis for H. G. Wells's *The War of the Worlds,* published in 1898.

The canal myth persisted for decades, despite the fact that Lowell's canals never showed up clearly in photographs and other astronomers did not see them. Belief in Martians remained widespread enough to create a famous panic during Orson Welles's 1938 radio broadcast of *The War of the Worlds,* when many people thought an invasion was actually under way. The debate about Martian canals and cities was not entirely put to rest until NASA's first two spacecraft to Mars—the Mariner 4 flyby in 1965 and the Mariner 9 orbiter in 1971—sent back images of a barren, cratered surface.

Today we can be quite certain that there is no great Martian civilization, and probably never has been. But the possibility of microbial life on Mars remains a hot topic in science. Moreover, several other worlds in our solar system now seem like possible homes to indigenous life. Thus we are led to Mystery 10 on our list: Is there life elsewhere in our solar system?





(Above) This photograph shows a working model of the Viking landers, identical to those that landed on Mars in 1976. It is on display at the National Air and Space Museum in Washington, D.C. (Left) This pair of before and after photographs, transmitted back to Earth by the Viking 2 lander, shows where the robotic arm pushed away a small rock on the Martian surface.

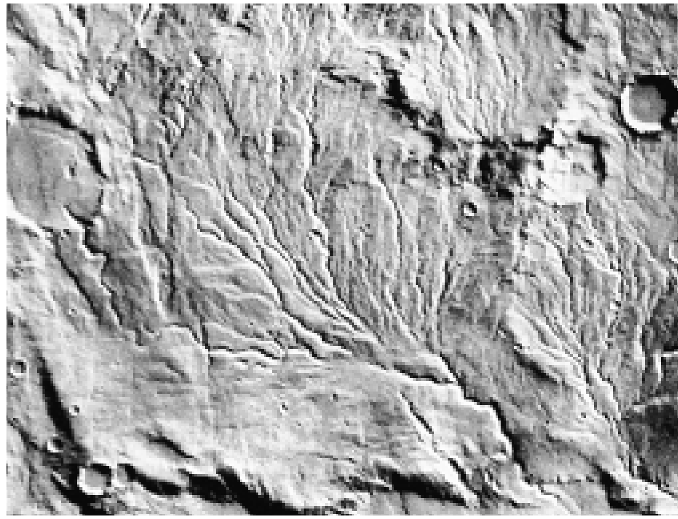
The first step in approaching this mystery is deciding just what it is that we're looking for. Even on Earth, biologists are not quite sure how to define life. Plants and animals and bacteria are all clearly living, but what about viruses, which cannot even reproduce unless they invade some other organism? If we tried to imagine every conceivable form that life might take, the list might well be endless. We cannot address such infinite possibilities all at once, so the best way to approach this mystery is by searching for "obvious" life—life that bears enough resemblance to life on Earth that we will know it when we see it. This search began when Viking 1 landed on Mars on July 20, 1976.

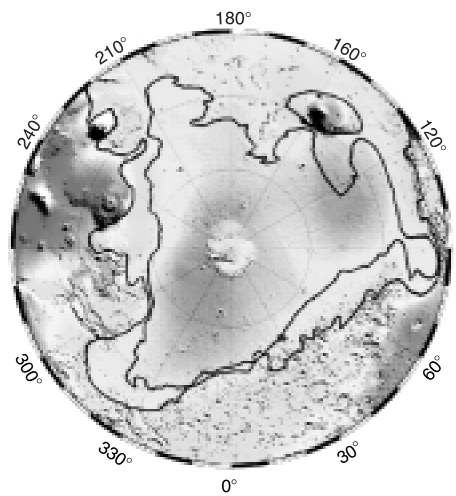
Mars is an appealing place to look for life, because it is the most Earth-like planet in the solar system, at least on the surface. Nevertheless, today's Mars would not be a very comfortable place to visit. The atmosphere is far thinner than that on the top of Mount Everest, and no human could survive more than a few minutes without a pressurized spacesuit. The temperature is usually well below freezing, and there is no liquid water anywhere. And because the atmosphere contains only trace amounts of oxygen and hence essentially no ozone (which is a form of oxygen), the Sun's deadly ultraviolet rays pass unhindered to the surface. Any Earth-like organism that left itself exposed would be quickly killed by this ultraviolet radiation.

But photographs of Mars taken by orbiting spacecraft reveal unmistakable evidence of a very different past—dried-up riverbeds, vast floodplains, and perhaps even a huge ocean. Clearly, water once flowed on the Martian surface, and that could have happened only if Mars once had a much thicker and warmer atmosphere. Although other geological evidence suggests that any oceans dried up at least 3 billion years ago (but photographs from Mars Global Surveyor suggest that some water flows may be much more recent), we have no reason to doubt that conditions on the young Mars were nearly as hospitable to life as conditions on the young Earth. Because life on Earth was already flourishing more than 3.5 billion years ago, it's easy to imagine that the same thing occurred on Mars. If so, Martian life may have found ways to survive—perhaps underground or in the icy polar caps—even as Mars itself became a cold, dry desert.

Viking 1 and its twin, Viking 2, were each equipped to search for Martian life in a fairly simple way. (Each was also accompanied on its journey to Mars by a Viking orbiter, which studied Mars from above.) Like all planetary missions to date, the Viking spacecraft made only one-way journeys. Observations and experiments designed to search for life had to be planned before the spacecraft were launched and were carried out robotically by the spacecraft on Mars. The spacecraft then transmitted pictures and other scientific data from Mars back to Earth. The Viking landers could not move about the surface at all, but each lander had a robotic arm that it used to push small rocks aside and scoop up samples of Martian soil. A few simple, automated experiments then analyzed the soil, searching for organic compounds and signs of biological activity, such as respiration. Although the experiments did show some surprising results, planetary scientists soon explained these as chemical rather than biological reactions.

The negative results from Viking were surely disappointing to many scientists, but the experiments did not rule out life on Mars. The Viking missions had, after all, sampled soil at only two relatively bland locations on Mars, which had been chosen because they made relatively easy landing sites, and the search was carried out by only a few simple experiments. But budgetary and political considerations, the grounding of the space program for three years after the tragic Challenger accident in 1986, and the failure of two Russian missions (Phobos 1 and 2) and one American mission (Mars Observer) to Mars all conspired to stop Martian exploration for some twenty years. The new era began with the landing of





(Top) This Viking orbiter photo shows dried-up ancient riverbeds on the Martian surface. (Bottom) This projection shows the Northern Hemisphere of Mars, with the North Pole at the center. Darker areas represent higher elevations. The black curves represent possible shorelines of an ancient Martian ocean.

Mars Pathfinder and its little rover, Sojourner, on July 4, 1997 (see Color Plate 2).

Pathfinder, a simpler and considerably less expensive spacecraft than Viking, landed on Mars in a rather innovative way. A parachute slowed its descent through the Martian atmosphere, but it still hit the surface at crash-landing speed. To protect itself, Pathfinder deployed airbags on the way down, which completely encased the spacecraft components. These airbags allowed it to bounce along the surface until it finally came to rest. Over the next several months, Pathfinder surveyed the landing site with cameras and other on-board instruments. Sojourner, which had been stowed on Pathfinder for the journey from Earth, slowly roamed the neighborhood. (Sojourner was named for Sojourner Truth, an African American heroine of the Civil War era who traveled the nation advocating equal rights for women and blacks.) Although Sojourner could travel only a few meters from Pathfinder, this was enough to check the chemical composition of many nearby rocks. The results confirmed what scientists had suspected: the landing site, in the Ares Vallis region, is a vast, ancient floodplain. Rocks of many types lie jumbled together as they were deposited by the flood, and the departing waters left rocks stacked against each other in the same manner that floods do on Earth.

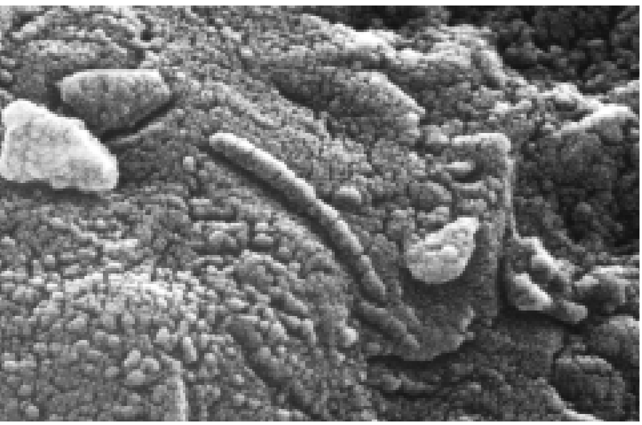
Pathfinder and Sojourner were designed more to test efficient and cheap new technologies than to search for life, but they marked the beginning of an ambitious invasion of Mars by spacecraft from Earth—and perhaps someday soon by human beings. As Earth and Mars orbit the Sun, the two planets are sometimes reasonably close (if 30 million miles can be called close) and other times much farther apart. When they are close, which happens roughly every two years, a journey to Mars takes about eight months with current technology.

NASA hopes to send two or more space probes to Mars at every one of these biennial opportunities over the next decade; however, the failure of both 1999 missions (the Mars Polar Lander and the Mars Climate Orbiter) may slow the parade somewhat while scientists and engineers figure out how to prevent similar losses in the future. Other nations, notably Japan and the member nations of the European Space Agency, also have plans for robotic missions to Mars. (The first Japanese mission to Mars, called Nozomi, was launched in 1998 but will not arrive until at least 2003, due to an engine misfiring shortly after launch.) The more sophisticated probes may carry rovers capable of journeying for many miles across the Martian surface in search of life.

Naturally, the search for life would be easier if we could bring a sample of Martian soil back to Earth, where we could subject it to analysis more detailed than is possible with automated probes that remain on Mars. NASA hopes to launch a sample-return mission to Mars as early as 2005, in which case we could have newly collected Martian rocks and soil in our hands as early as 2007 or 2008.

Surprisingly, that would not be our first sample of Mars, as scientists believe that a few meteorites may have a Martian origin. Almost all meteorites share common characteristics which tell us that they are either pieces of rock left over from the formation of our solar system or pieces of shattered asteroids. (Indeed, radioactive dating of the most ancient meteorites is what tells us that our solar system formed 4.6 billion years ago.) But a few meteorites have unusual compositions that suggest a different origin. These rare meteorites seem to be chunks of rock from the surface of the Moon and Mars. Based on what we know about the chemical composition of Mars from the Viking landers, fifteen of these meteorites (as of this writing) have compositions that are near perfect matches for what we expect in rocks from Mars.

In 1996, a team of NASA scientists claimed that one of these Martian meteorites, known as Allan Hills 84001, or ALH 84001 for short, contained evidence of past life on Mars. Meteorite ALH 84001 had been scooped from the Antarctic ice by a team of meteorite hunters in 1984. Careful study of the meteorite reveals its story. Radioactive dating shows that the underlying rock formed from volcanic lava, presumably on the surface of Mars, about 4.5 billion years ago. Sometime later—probably about 3.6 billion years ago—the rock was heated and deformed, so that a liquid was able to flow through it and deposit small rounded globules of material. Much more recently, the rock was heated again, this time by the impact of an asteroid that blasted it off the Martian surface. In space, the meteorite was exposed to cosmic rays—high-energy particles that leave telltale chemical signatures on anything unprotected by an atmosphere. Careful analysis of ALH 84001's cosmic ray exposure shows that it wandered through the solar system for at least 16 million years. Then, about thirteen thousand years ago, it came crashing down to Earth, landing in Antarctica.

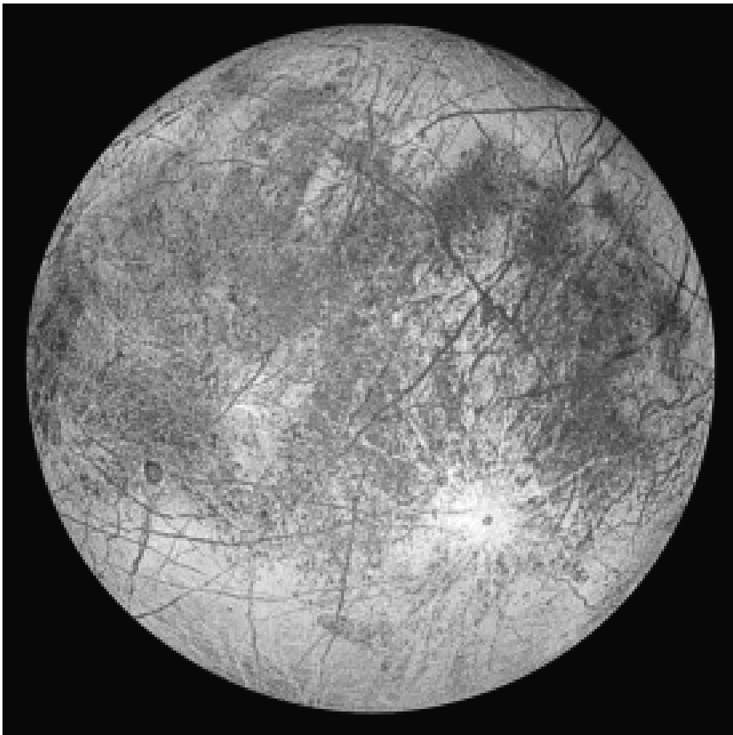


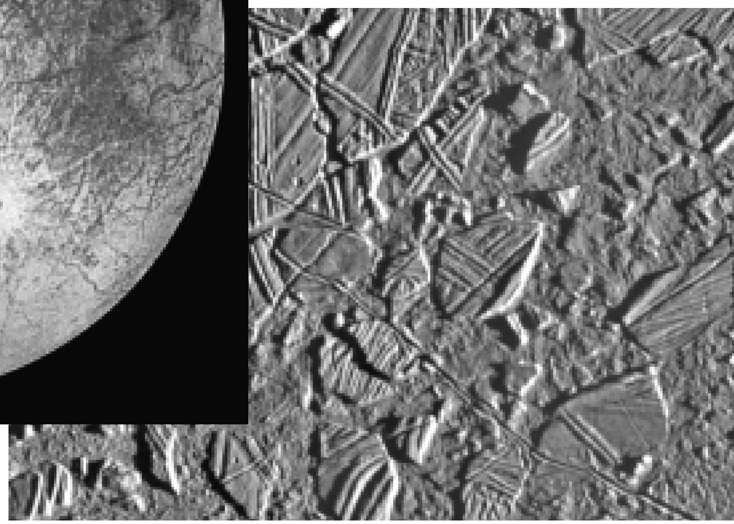
(Top) Meteorite ALH 84001 weighs a little less than 5 pounds and measures about 6 inches long by 4 inches by 3 inches. It is apparently a rock from Mars. (Bottom) Some scientists believe that the rod-shaped structures seen in this microscopic view of a thin section from ALH 84001 are fossils of microbial Martian life, but most others are skeptical.

The globules found in ALH 84001 contain chemical evidence suggestive of life, including layered carbonate minerals and complex molecules (polycyclic aromatic hydrocarbons)—both of which are generally associated with life when found in Earth rocks. Even more intriguing, under high magnification the globules reveal eerily lifelike, rod-shaped structures. However, while some scientists suggest that these structures might be fossils of microscopic Martian life, others argue that all the so-called evidence for Martian life in ALH 84001 could have been produced by nonbiological processes. This extraordinary debate about whether we already have discovered evidence of life beyond Earth will undoubtedly continue as scientists subject ALH 84001 and other Martian meteorites to further scrutiny. Unfortunately, unless there is a surprising and major breakthrough, it is unlikely that the meteorites by themselves can provide definitive evidence of life. For that, we will have to rely on the planned armada of spacecraft bound for Mars.

Not long ago, most scientists would have said that Mars was not only the best place to look for life in our solar system but the *only* place. Our Moon and the planet Mercury are both cratered worlds without atmospheres, and clearly could not harbor life as we know it. Venus is a near twin to Earth in size, but its thick carbon dioxide atmosphere creates a strong greenhouse effect that bakes its entire surface to 450°C (900°F)—far hotter than a pizza oven. In addition, the weighty atmosphere bears down on the surface with a pressure equivalent to that nearly a kilometer beneath the ocean surface on Earth, and the Venusian clouds contain sulfuric acid and other corrosive chemicals. Such conditions make it difficult to imagine life on Venus. With Mercury, Venus, and the Moon ruled out, and Mars already considered, we are left with the worlds of the outer solar system. These worlds and their moons are magnificent, but they are very far from the Sun. Whereas Mars orbits the Sun only about half again as far away as Earth, Jupiter orbits at five times the Earth's distance, and the other outer planets (Saturn, Uranus, Neptune, and Pluto) are much farther still. Sunlight is too weak to provide the energy needed for life on these distant worlds. But who needs sunlight?

Until fairly recently, most scientists would have answered, "All life forms do." But the past few decades have seen extraordinary discoveries about the abodes of life on Earth. Biologists have found microorganisms living deep inside rocks in the frozen deserts of Antarctica and inside rocks buried nearly a mile underground. Perhaps most important to the search for life beyond Earth, scientists have found teeming life near deep undersea volcanic vents. This life does not in any way depend on sunlight, instead receiving all its chemical energy from the heat of the Earth itself. Moreover, genetic analysis of life-forms around the volcanic vents suggests that they may be more closely related to the common ancestor of all life on Earth than any other living organisms. Many biologists therefore believe that life may have first arisen around volcanic vents, with sunlight-dependent life coming only later. If so, then the water around undersea volcanoes might be





(Left) A global view of Europa shows a fractured crust nearly devoid of craters. (Below) This close-up of Europa's surface shows jumbled crust in which icebergs are apparently frozen in slush. (Photos taken from NASA's Galileo spacecraft.)

the best place to find life in our solar system—and we know of at least one place beyond Earth where such volcanoes may be found.

Europa is one of four large moons that orbit Jupiter, along with a dozen smaller moons. Europa was first seen through a telescope by Galileo, but we had no close-up pictures of it until the Voyager 1 and 2 flybys in 1979. Photographs of Europa show a surface with very few impact craters. In a solar system filled with rocky debris, a nearly crater-free surface can mean only one thing: some process is continually erasing the evidence of impacts. Because Europa's surface is made almost entirely of water ice, it seems likely that the craters have been erased by flowing water. Europa is therefore thought to have a huge subsurface ocean beneath its icy crust. Recent, detailed photographs taken by the Galileo spacecraft—which has been orbiting Jupiter since

1995—support this basic scenario. Moreover, the structure of the surface ice suggests at least occasional heating from below, presumably by volcanoes sprouting from the floor of Europa's ocean (see Color Plate 3).

With a deep ocean and a source of energy in its undersea volcanoes, Europa may be even more likely to harbor life than Mars. Indeed, if biologists are correct in guessing that life on Earth first evolved near undersea volcanic vents, an absence of life on Europa may be more difficult to explain than its presence.

Not surprisingly, Europa is now a prime target for scientific exploration. NASA is currently developing plans for a Europa orbiter that could be launched as early as 2003 to reach Europa in 2006 or 2007. This mission would carry a radar instrument designed to establish whether or not Europa really has a subsurface ocean, and perhaps how much liquid water lies beneath the icy crust. If the existence of an ocean is verified, a follow-on mission would send a spacecraft to land on Europa, where it would use battery-generated heat to melt its way through the crust and into the ocean. There's no telling what such a mission might find, from microbial life to creatures larger than whales.

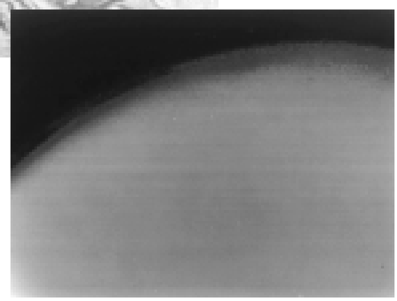
Europa provides the clearest case to date for a subsurface ocean, but Ganymede and Callisto, two other moons of Jupiter, may also have such oceans. These worlds, too, have icy surfaces, but their larger numbers of craters show that water flows occur less commonly, if at all. Nevertheless, it's certainly worth looking for life on both of these moons as well. Imagine the irony if we found life on all three. There might be more inhabited worlds around the far-flung planet Jupiter than in the rest of the solar system combined.

Hopes for finding life dim beyond Jupiter, but a few scientists hold out the possibility of life on Saturn's moon Titan. Although we usually think of moons as being airless, Titan has a thick atmosphere—like Earth's, it is made mostly of nitrogen. The surface pressure is only slightly greater than that on Earth, which means that it would be fairly comfortable if not for the lack of oxygen and the bone-chilling temperatures. Titan is far too cold for liquid water today, but the heat of impacts early in its history might have created slushy ponds in which life potentially could have arisen. If life did arise, perhaps some organisms survive to the present day in geological hot spots or somehow adapted to survive despite Titan's icy temperatures. We do not yet know what Titan's surface looks like, because the thick atmosphere hides it from view. However, the combination of atmospheric composition and surface temperature, both of which have been measured, leads many scientists to believe that Titan may be partially or fully covered by a deep ocean of liquid ethane.

Answers about Titan may be coming fairly soon, because a spacecraft called Cassini is scheduled to arrive there in 2004. Cassini was launched in 1997 and carries a radar instrument that should allow us to map Titan's surface in detail. It also carries a probe called Huygens (named for the seventeenth-century astronomer who discovered Titan), which it will drop to the surface of Titan. Just in case, the probe is designed to float in liquid ethane.

We have now identified five places in our solar system with a reasonable chance of harboring Earth-like life: Mars, Europa, Ganymede, Callisto, and Titan. If we allow for less likely locations, the list expands even more. The four giant planets of our solar system—Jupiter, Saturn, Uranus, and Neptune—have no solid surfaces upon which to look for life, but their atmospheres are rich in the chemical building blocks of life, and at some depths the temperature would be quite comfortable for life. Although it is difficult to imagine how life might arise in the air in the first place, once it got started life might survive just fine—as long as it found some way to stay at a comfortable depth despite the turbulent atmospheric currents.

A more speculative idea suggests that life might exist on comets, which we know to contain large amounts of organic material. A few scientists have even suggested that life on Earth may have been brought here by a comet. If so, comets may have seeded life on many other worlds. Moreover, the presence on Earth of meteorites from Mars tells us that planets occasionally exchange rocks dislodged by major impacts. The harsh conditions under which some life on Earth exists suggest that living organisms might survive such impacts and the long journey from one planet to another. In that case, life may have migrated among



The inset (right) is a photograph of part of Titan from Voyager 2. Note that it is completely enshrouded by its thick atmosphere. The artist's conception (above) shows what the surface might look like as the Huygens probe descends in 2004. Saturn and the Cassini orbiter are faintly visible through the atmosphere. (Artistic license has been taken to make the orbiter look big enough to be seen from the moon's surface.)

the planets just as various species spread among islands on floating debris. Life from Earth may have made its way to Mars—or vice versa. If we ever discover life on another world, we should be able to tell whether it shares a common origin with life on Earth by examining its set of genetic instructions.

The search for life may well be a never-ending quest. If we don't find it, we can always believe that we simply haven't yet looked hard enough or in the right places. But whether or not we find life, the exploration of Mars, Europa, and Titan planned for the next decade should provide deep insights into the conditions under which life can survive. And if this coming exploration does find life on other worlds, our Mystery 10 will be solved before the third millennium is barely under way.