Before he fell to his death in the Antarctic mountains, microbiologist Wolf Vishniac helped pioneer the search for life in extreme environments. Today, his work lives on in our quest to detect life on Mars.

BLUE MARBLE, RED PLANET

BY MARISSA GRUNES

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NASA'S PERSEVERANCE rover inspects rock with its robotic arm, as it seeking signs of past microbial martian life, in this artist's illustration.

FOR THE FIRST TIME IN THE HISTORY OF OUR SOLAR SYSTEM, HUMANS ARE COLLECTING ROCKS from another planet. Since the Perseverance rover landed on Mars in early 2021, NASA scientists have been guiding it across the Jezero Crater, an ancient martian lakebed. When the rover reaches a site of geological interest, it drills out a small rock sample and seals it in a tube.

These bits of the martian surface (around 2.5 inches long and roughly as thick as your pinkie) are expected to arrive on our planet in 2033. It's the latest in a series of technologically breathtaking missions that have opened Mars to us since 1965, when the Mariner 4 spacecraft sent back the first bleak photographs of the planet's surface.

So far, our efforts on Mars haven't answered the big question: Are we alone in the universe? Instead, we've discovered in the Red Planet a mirror to our own blue marble. Mars' windswept rocks hold clues to the first billion years of Earth's history — the very period when life emerged here.

The vital exchange between martian and terran exploration has inspired missions like Perseverance and those lined up to follow. It's the same interplanetary dream that sent Wolf Vishniac, one of the earliest martian pioneers, to the most hostile environment on Earth.

VISHNIAC BENT his head against the freezing wind, squaring his shoulders under a pack loaded down with scientific equipment. A crust of ice clung to his reddish beard as he trekked along a rough path in a place where winds gust to 100 miles an hour, scouring away moisture from the stone landscape. Vishniac was climbing into Antarctica's Asgard mountains, rising above the McMurdo Dry Valleys. As he hiked, he collected rocks that might show signs of life in a frozen wasteland, with the hopes of advancing the search for life beyond our planet.

Vishniac loved mountains. When he had arrived at the Asgard Range in

VISHNIAC, an avid camper and backpacker, stares out across the McMurdo Dry Valleys in Antarctica during his 1972 expedition.

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1972, he knew he'd be relying on his mountaineering experience as he tested ways to detect life in extreme environments. His goal had been Mars, but Antarctica was the next best thing.

For over a decade, Vishniac had been developing an experimental method for identifying life on Mars. In 1959, the German-born microbiologist had won NASA's first-ever grant in the biological sciences; his aim was to develop a prototype instrument for detecting microorganisms remotely on other planets. His instrument, nicknamed "the Wolf Trap," would drop soil particles into a tube containing liquid nutrients. If the fluid clouded up, that would suggest the growth of bacterial cultures. Think of leaving a glass of apple juice in the sunlight; it becomes hazy as microbes digest the sugars and multiply.

The Wolf Trap inspired a new field: extraterrestrial microbiology. The study of microbiology itself was very young; taking it to another planet seemed downright outlandish. Other biologists accused Vishniac of wasting time, but he was undeterred. "When he decided he wanted to do something, he would go do it," his son Ethan says. Vishniac thought big. He admired the science fiction writer Olaf Stapledon, whose novels imagined future human evolution on Earth. Vishniac was fascinated by Stapledon's "sweep of imagination, trying to tell the story of humanity as if it were a story about any other species," Ethan says.

The Viking mission to Mars would make Vishniac's own sweep of imagination real. The mission was designed to put two landers on opposite sides of the planet, where each would scoop up a sample of martian dust, called regolith. Then Viking's scientists would remotely conduct a series of biological and chemical experiments to test for the presence of life or, at the very least, the organic molecules that are life's chemical building blocks. When the mission finally landed in 1976, it would be the first time humans had conducted experiments on another planet.

The project's principal investigators faced a daunting challenge: design highly controlled experiments to be activated 200 million miles away, without assuming that martian life would work the same way it does on Earth. Their solution was to detect byproducts of respiration or metabolic activity — the functions that all life seems to undertake — rather than look for specific types of cells. For instance, one experiment placed a soil sample into a chamber with several gases that animal and plant life on Earth are known to breathe, including oxygen and carbon dioxide. The instrument then measured changes in the relative concentrations of these gases over time.

THOUGH VISHNIAC had been one of the mission's visionaries from the start, his Wolf Trap never flew. It was cut from the Viking payload in 1971, deemed too heavy and unlikely to offer conclusive results. After learning the Wolf Trap wouldn't be included, Vishniac decided to test his instrument on an alien landscape closer to home: the hyper-arid polar desert of Antarctica's Dry Valleys.

The Dry Valleys are the closest thing to Mars on Earth. When British explorer Robert Scott discovered the region in 1903, he thought it beautiful and bleak. "It is certainly a valley of the dead," he wrote. For over half a century, most visitors agreed. One of the Viking investigators, Norman Horowitz, had even gone to the Valleys in the 1960s to refine methods for martian life detection. He and his colleagues found that the drier parts of the Valleys contained soils with "no detectable microorganisms."

But in 1972, the Wolf Trap showed that Horowitz and his colleagues had been wrong. Vishniac took samples from areas within the Valleys so dry that the particles became statically charged and jumped away from the collecting bag. Yet the addition of sterile water to this soil in the Wolf Trap revealed the rapid growth of bacterial cultures. The next year, in 1973, Vishniac returned to the Asgard Range to continue this work.

On Dec. 10, 1973, Vishniac left his two-person camp for an exploratory hike. When 12 hours passed and he hadn't returned, his colleague set out to look for him, expecting to encounter Vishniac engrossed in a new discovery. Instead, he found that Vishniac had strayed from the marked trail; a search team discovered his body at the bottom of an icefield between two mountains. It appeared Vishniac had fallen 500 feet down a steep mountain slope to his death.

When Viking landed on Mars in 1976, its instruments — the Wolf Trap not among them — sent back a wealth of contradictory data. Carl Sagan described the results as "tantalizing, annoying, provocative [and] stimulating." All three biological experiments detected the desired byproducts of respiration or metabolic activity, but none could confirm that biological processes had created them. One instrument returned results at temperatures that seemed inconsistent with biological life; in another case,

OUT OF ALL OF Earth's diverse landscapes, the McMurdo Dry Valleys may resemble Mars the most closely due to their exceedingly dry, cold conditions.

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VISHNIAC (RIGHT) POSES with University of Rochester graduate student Stanley Mainzer, who accompanied him on his voyage to Antarctica in 1972.

SINCE FRIEDMANN'S DISCOVERY, SCIENTISTS HAVE FOUND LIFE IN OTHER SEEMINGLY IMPOSSIBLE PLACES.

IMRE FRIEDMANN, seen here in the McMurdo Dry Valleys, was a microbiologist and among the first to find that microbial life can survive in extreme environments.

concentrations of oxygen spiked far too quickly to resemble respiration. It was also impossible to rule out non-biological chemical reactions — in other words, false positives. Then a fourth experiment failed to find any organic compounds in the soil, a result that may have been a false negative. These results ignited a debate that continues today.

The ambiguities swirling around Viking cast a shadow over the nascent field of extraterrestrial life detection. The search for life on Mars was starting to look like very expensive sci-fi fanaticism; after Viking, NASA moved away from life detection on other planets.

On Earth, though, Vishniac's death marked an unexpected new beginning.

WHEN VISHNIAC'S widow Helen received items from his field camp, she found a bag of rocks labeled "for Imre Friedmann." Friedmann, a microbiologist, had been looking in Israel's Negev Desert for a kind of life called cryptoendoliths, microbes that hide inside rock. The Antarctic sandstone samples that Helen forwarded to Friedmann in 1974 had a telltale coloration pattern: a layer of green, underlain by orange and then shading into white rock. Friedmann confirmed what few would have imagined — there weren't just organisms living in the rock, but a thriving microscopic ecosystem.

Since Friedmann's discovery, scientists have found life in other seemingly impossible places. Around the same time, researchers from Woods Hole Oceanographic Institute discovered life in deep-sea hydrothermal vents, where it had been thought nothing could survive the searing hot temperatures. Life has since been found in hot volcanic rock deep beneath the Pacific Ocean, in toxic mining sludge, even growing on the walls of Chernobyl. These organisms are called extremophiles, for the obvious reason that they populate extreme environments. And new examples continue to turn up: In 2020, a team was shocked to find dense microbial communities in cold, ancient ocean crust, thriving on methane and decomposed organic material tens of millions of years old. Such microbial life — often single-celled bacteria or archaea — has evolved to survive and multiply without things like oxygen and sunlight that we once thought essential.

These discoveries have lent fresh perspective to the search for life on other planets. When Mars fell out of favor, scientists busied themselves understanding otherworldly places right under our noses — and the field of astrobiology took off without ever leaving our planet. But if astrobiology has revealed that Earth is honeycombed with life, the opposite seems true of Mars. The more we learn about the Red Planet, the harder it is to stay optimistic.

With each fresh disappointment, researchers have revised their approach: take more photographs, conduct experiments, seek water beneath the surface. "A question that I was asked recently is: 'When do we give up on Mars?'" says Mary Voytek, the head of NASA's Astrobiology Institute. "When do we decide [that] we've looked enough?" Voytek says she doesn't know the answer, but that there are still many martian regions that remain "untapped."

If anything, the scope of martian exploration has expanded in recent years. Three nations launched Mars missions in 2020, including China and the United Arab Emirates, while India and the European Space Agency have missions planned for this decade.

Many of these missions are guided by what we learned — and failed to learn — from Viking. The results of the Viking experiments were, as Sagan put it, "annoying." Today, they're perhaps more annoying than ever. The fact that one experiment found no organic compounds suggested to researchers that the martian surface was effectively dead. But in 2008, the Phoenix Mars Lander discovered that martian dust is laced with perchlorate, an ingredient in rocket fuel. It suddenly appeared likely that the Viking experiment had itself sterilized the regolith: By heating the sample to 500 degrees Celsius (over 900 degrees Fahrenheit) before testing it, the instrument had ignited the perchlorate and destroyed any organics that might have been present. "It just bleaches the organics out," says NASA astrobiologist Chris McKay.

When the Curiosity rover conducted a similar experiment in 2012 without applying so much heat, organic compounds showed up, albeit at very low levels. These more recent findings have prompted researchers to revisit Viking's ambiguous biological findings. Indeed, one of the Viking mission's principal investigators, Gilbert Levin, argued until his death in 2021 that one of his experiments had found signs of life in martian soil.

Such views fly in the face of everything we think we know about life. Mars has a thin atmosphere and no liquid water on the surface, and is irradiated by ultraviolet light and high-energy particles known as cosmic rays, which destroy organic molecules. In short, the planet's conditions suggest that the best possible explanation for the Viking results is nonbiological.

But life is not easy to pin down. For starters, it's difficult to formulate a precise and thorough definition of life that captures biological variety while excluding those phenomena, like viruses, that grow and replicate but aren't considered alive. In 1994, a NASA committee defined life as a "self-sustaining chemical system capable of Darwinian evolution." This definition hits on several key characteristics: a *chemical system* implies metabolism and growth; *self-sustaining* implies reproduction; and *Darwinian evolution* implies a system of genetic inheritance, which we know as DNA.

Life on other planets, however, may not share the same chemical basis. Martian genetic material might not look like our DNA and martian metabolic chemistry may be unrecognizable. "An agnostic approach is needed to look for evidence of life [on Mars]," says Michael Meyer, lead scientist for NASA's Mars Exploration Program. That means suspending assumptions and starting simple.

WHEN THE PERSEVERANCE rock cores arrive, scientists will indeed start simple: Meyer explains that analysis will be "geared toward looking for complex organic molecules and going from there." Meyer lists two initial questions that direct sample selection: Do the samples have organics, so we can look for signs of life? And do the samples include igneous rocks to calibrate dating? Where these criteria are concerned, the project has already been a success. The 15 cores that Perseverance collected in the first year and a half of its mission include igneous rock, sedimentary rock (where life most often lives on Earth), samples indicating past interaction with water, and samples containing organic compounds. "This cache is already checking all the boxes," Meyer says.

Even if we don't find signs of life in these rocks, though, we will learn something from them. The oldest evidence for life on Earth dates back around 3.7 billion years. Intriguingly, we know that Mars was habitable at around 4.1 billion to 3.7 billion years old, during a period called the Noachian,

IN 1977, scientists made the stunning discovery that deep-sea hydrothermal vents can harbor exotic organisms.

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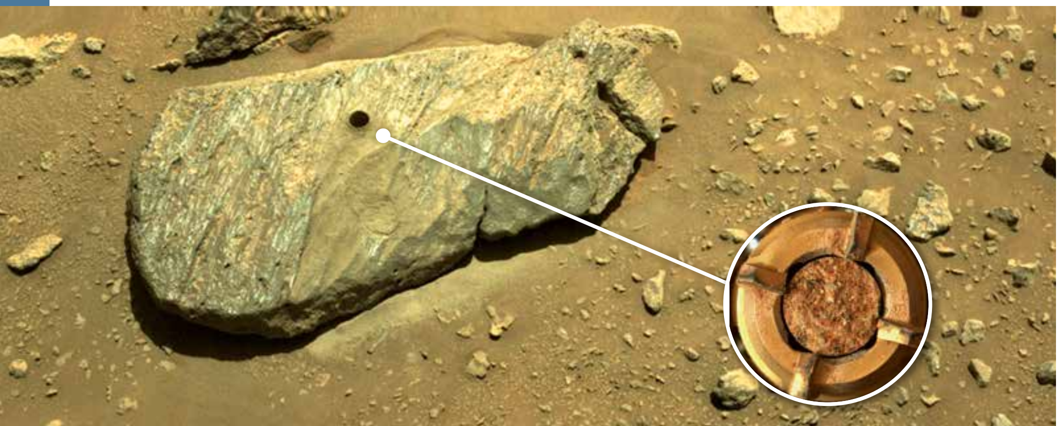
NASA/DALE ANDERSON



THESE IMAGES show a cylinder of rock (roughly the size of classroom chalk) that Perseverance extracted in 2022. Below, a conceptual illustration depicts a robot that would return the samples to Earth.

named after Noah's flood. In the Noachian, Mars was relatively warm, had an atmosphere protected by the planet's magnetic field, and most importantly, had lakes, rivers, and even oceans on its surface. At some point, Mars' liquid core stopped churning and the magnetic field disappeared, allowing the atmosphere to dissipate into space and leaving a cold, dry surface baking in deadly cosmic radiation.

If Mars had plate tectonics, those also stopped long ago. This means its rocks don't cycle back into the mantle and re-melt as consistently as Earth's do. Less than 5 percent of Earth is composed of rocks from the planet's first billion years. But on Mars, "whatever was going on in the first billion years is preserved," says Meyer. "Over 50 percent of the surface is ancient rocks." A look into the martian past might illuminate the black box of our own planet's earliest history.

The hope of finding life on Mars, even if long-since fossilized, may be slim. Yet it continues to excite speculation — and contention. After a 2021 paper in *Nature Astronomy* sparked widespread debate that the clouds of Venus could be habitable, Voytek and other NASA leaders put forward a set of guidelines for reporting evidence of life beyond Earth. These guidelines urge researchers to avoid "definitive" language and to "emphasize that false starts and dead ends are an expected part of a healthy scientific process." Our search for life on Mars may be littered with false starts and dead ends, but researchers like McKay believe it would be scientifically irresponsible to dismiss long-shot ideas just because they haven't been proven. We may never be able to disprove the existence of life on Mars, either.

Regardless of what we find in the Perseverance cores, there will undoubtedly be other missions. Already the European Space Agency's ExoMars program — a pair of missions designed to determine if martian life ever existed — is planning to drill deeper into the surface than Perseverance. The implications of these efforts extend beyond Mars, too.

Where Vishniac sought alien environments on Earth to study Mars, today we are looking at martian rocks to understand the formation of our solar system and the conditions in which life arose on Earth. When those rock cores land in the Utah desert aboard a returning spacecraft, they will carry windows into our own past. ■

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FROM TOP: NASA/JPL-CALTECH (2); NASA/JPL-CALTECH/ASU/MSSS (2)