Fossil-Hunting on Mars

by Jack D. Farmer SETI Institute

Today, Mars is probably a dead world. The *Viking* missions in the mid-1970s found no organisms, and martian surface conditions are inhospitable. The surface lacks liquid water, a requirement for life as we know it; any water would boil away into the thin atmosphere, which is equivalent to a height of about 35,000 meters (115,000 feet) on Earth. Oxidants in the red soils of Mars destroy organic molecules, and ultraviolet radiation at the martian surface would fry microbes. No terrestrial organisms subjected to similar conditions in a lab have survived. Martian life might huddle in underground oases, like the subsurface environments on Earth where chemosynthetic microorganisms thrive, but we will not be able to drill into the martian subsurface for years to come. So where should upcoming missions look for life?

Long ago, Mars might have been hospitable enough for microorganisms to develop. The climate of early Mars was more like the Earth's, with abundant water and a denser, warmer atmosphere. Photos from the *Mariner* and *Viking* orbiters show channel systems in the older regions of Mars, similar to those produced by rivers on the Earth. These channels often surround basins where water could have formed lakes.

At the same time when liquid water apparently was present on Mars, life arose on Earth. Terrestrial life developed between 4.1 and 3.5 billion years ago. Before then, the crust was molten. The oldest life forms — which resemble modern-day cyanobacteria, simple photosynthetic microbes that form layered sedimentary structures called stromatolites — occur in rocks 3.5 billion years old. If life developed on Earth during this period, it might have developed on Mars, too.

If it did, it probably left fossils. This prospect has spawned a new field of science called "exopaleontology." Exopaleontologists are working on a strategy for fossil-hunting. Mars is big, and we can't go just anywhere and except to find fossils.

The fossil record in the oldest rocks on Earth, formed during the time in history called the Precambrian, consists of remnants of microbes and the chemicals they left behind. The preservation of microorganisms did not occur everywhere: It required certain geologic conditions and environments. Precambrian fossils consist mostly of stromatolites, produced by stratified microbial communities called "mats." Inside stromatolites, paleontologists sometimes find preserved cells of microorganisms and the organic compounds they produced. But this happens only where organisms were quickly entombed by minerals that precipitated in their environment while they were still alive.

Micro-sarcophagi

This rapid entombment is most common in water-rich environments, especially nutrient-rich springs that bubble to the surface and deposit their dissolved minerals. Thermal springs, such as the geysers of Yellowstone, and cooler springs, such as those that form the tufa towers at Mono Lake, are good examples. These also tend to be environments that are particularly rich with microbial life. I have been studying these places to better understand how spring deposits preserve biological information. Studies by analogy have helped to improve fossil-hunting on Earth and to narrow the sites where fossils could reside on Mars.

In the movie *Jurassic Park*, rapid entombment by minerals preserved organisms and their DNA. Although preservation in amber can have spectacular results, this mineral (actually fossilized tree resin) weathers quite easily and is comparatively uncommon in the geologic record. For long-term preservation, over billions of years, the minerals that entomb organisms must be chemically stable and impermeable to water. Only in this way can they seal out the environment and shelter the organic materials from decay. If exopaleontologists want to find 3.5 billion year-old fossils on Mars, they must target not only the most common minerals, but also the most stable: those that resist the ravages of weathering, and retain their biological information after long-term burial.

The most widespread such minerals are silica, calcium carbonate, and fine-grained clays. All well-preserved organic fossils in the Precambrian on Earth are found in these minerals. Silica is composed of the two most abundant elements in the crust, silicon and oxygen. Calcium carbonate, the mineral making up limestone, is common in ancient rock sequences on Earth. Clays are good sources for Precambrian organic matter, although they undergo significant compaction following deposition, flattening fossils into thin films.

Other minerals also entomb microorganisms, but are unstable and therefore rare. For example, common table salt (halite) frequently entraps microorganisms when it crystallizes from solution, but it dissolves too easily. Another material that encases organisms is ice. Creatures have been preserved in ice for millions of years. But the oldest ice on Earth is still young in geologic terms. There have been many periods in the Earth's history when the planet was much warmer and the poles were ice-free. The same is true of Mars. Near-surface ice is stable on Mars only at high latitudes.

Planetary geologists do not know whether Mars has widespread deposits of silica, calcium carbonate, and clays. The *Mars Global Surveyor* mission will look for them, but until then we can make some educated guesses. Carbonates are an interesting case-study. Most models for the early atmosphere of Mars assume a much denser atmosphere of carbon dioxide. Carbon dioxide in the martian atmosphere gradually combined with rocks to form carbonates, and eventually all the carbon dioxide was removed from the air: a sort of inverse global-warming.

Carbonates form on Earth, too, but we avoid planetary death because plate tectonics recycle carbon dioxide. The carbon dioxide in the air combines with the rocks of the crust. It also dissolves in oceans and lakes, where it precipitates to form carbonates or becomes fixed by organisms that eventually die and are buried. Plate tectonics drag these materials back into the Earth's interior. There, the rocks melt and release the carbon dioxide back into the atmosphere through volcanic eruptions.

Death to the Martians

The absence of a recycling mechanism on Mars doomed any early biosphere. The atmosphere disappeared, never to return. In the process, the planet accumulated carbonate deposits and salts like halite. Similarly, other rocks that are rare in ancient areas on Earth, such as evaporites, may be quite common on Mars. These rocks were probably never buried or disturbed by the tectonics that constantly reshape the Earth's surface. The rocks in these ancient southern highlands of Mars have likely survived with little change.

If spacecraft can find aqueous mineral deposits in those ancient highlands, they will have found the best place to hunt for fossils. Spacecraft orbiters have instruments to look for key minerals like silica and carbonate, using high-resolution photography (to identify geologic features) and infrared and gamma-ray spectroscopy (to identify the minerals). After we know where to look, robots can collect and analyze samples. If all goes well, this will begin in 1997 with *Mars Pathfinder*.

Mars Pathfinder will land near the spot where the large channels of Ares and Tui Valles systems spill out onto Chryse Planitia. The outflows that carved these channels originated from collapsed terrain called thermokarst. These features probably formed when subsurface geothermal heat melted ground ice. Life might have thrived in such areas. Outflows would have swept fossils down the ravines to the *Pathfinder* landing site. Perhaps the *Pathfinder* rover will give us our first glimpse of hydrothermal mineral deposits on Mars, and maybe even a thermal spring stromatolite.

But what if martian life never developed? Even if the aqueous minerals do not bear fossils, they will contain pockets of martian fluid. The fossilized fluids would tell us what the terrestrial planets used to be like, and thereby help biologists to understand how life evolved on Earth. Whether Mars is dead or alive, it hold the key to unraveling the mysteries of life.

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