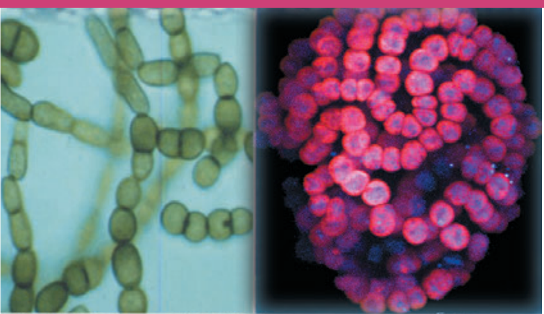
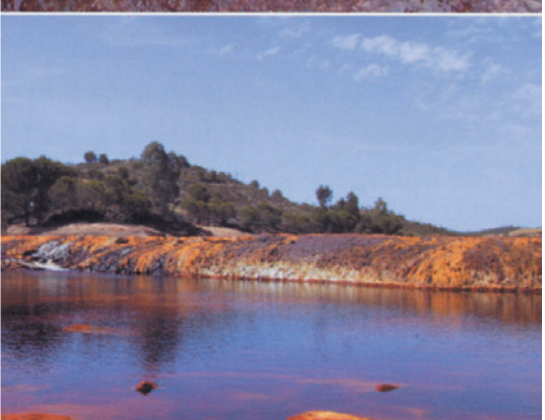
Astrobiology

The study of the origin, evolution, and distribution of life in the universe.





by Daniella Scalice and Krisstina Wilmoth

What exactly does it mean to be alive?

Life as we know it here on Earth exchanges energy and materials with the environment. Life forms grow, develop, produce waste products, and reproduce, storing genetic information in DNA and RNA and passing it from one generation to the next. Life evolves, adapting to changes in the environment and changing the environment in return. The basic unit of living things is the cell. Life is based on the chemistry of carbon and requires liquid water.

The "liquid" part is important. It's very hard to transport important substances, like nutrients or metabolites, from one place to another within a solid, and it's hard to control that transport in a gas. Liquids can do it well.

Water has many qualities that make it an ideal medium for the cellular biochemical reactions necessary for life. The chemical properties of water molecules help the other molecules of life, such as DNA, proteins (structural building blocks of cellular architecture and enzymes that speed up chemical reactions), and sugars (such as glucose, a common sugar used for energy), orient themselves in the proper three-dimensional shapes needed to carry out their functions in the cell. In order to maintain osmotic balance (and avoid drying out or swelling up), cells also need dissolved salts such as calcium and potassium. Water has wonderful capabilities to dissolve the nutrients and salts on which life depends, and the ability to move these molecules into and out of cells as it flows.

Water is the only chemical compound that is found naturally on Earth in all three physical states—as a gas, a liquid, and a solid. This property allows water to cycle through evaporation, condensation, and precipitation, between reservoirs in the oceans, on land, and in the air. Indeed, water is one of the few substances that can be liquid at the temperatures and pressures typical of

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the Earth's surface (mercury and liquid ammonia are the others). Water will remain liquid over an extremely large range of temperatures, freezing at 0°C (32°F) and boiling at 100°C (212°F). All of which means that temperatures on Earth can undergo rather large variations before the liquid water freezes or boils away.

With all this flexibility, it is no wonder that every form of life found on Earth requires liquid water for at least part of its life cycle. And it is expected that life forms elsewhere will display this same requirement. Perhaps there are life forms evolved upon alternative chemistries and solvents, but a full-scale scientific search for life in the solar system and ultimately the universe—a search based on our experience of life on Earth—has to start somewhere. So it makes perfect sense to "follow the water."

What do astrobiologists do?

Astrobiologists—representing many scientific disciplines—use their studies of the nature of life on Earth to inform the search for life elsewhere, including advising on upcoming solar system exploration missions, and devising innovative means of remotely detecting the signatures of life. Astrobiologists study extreme environments on Earth and characterize the life forms that occupy them. These environments provide Earthly analogues to environments on other planets, and a framework for thinking about the organisms that once did or may now inhabit them. The activities on poster included with this issue are designed to explore this connection.

Extreme environments

On Earth, life is found anywhere liquid water is present. Only in the past few decades scientists have realized that "anywhere" includes such extreme environments as ice-covered Antarctic lakes, hydrothermal vents on the ocean floor, and porous cracks in deep subsurface rocks. The organisms that live in these harsh conditions are called *extremophiles*. They survive and sometimes thrive in environments once thought too hot, too cold, too salty, too acidic, too high pressure, too dry, or with too much radiation for life to exist.

For example, scientists have long known that microbial mats (large colonies of microbes) are responsible for the beautiful colors observed in Yellowstone National Park's many hot springs. The water in these springs tops 90°C (188°F), much too hot to touch. Some hot springs are also extremely acidic, with pH levels, in a few cases, similar to that of stomach acid. Yet life thrives in and around them.

In 1977, scientists were stunned to discover abundant life clustered around hydrothermal vents on the ocean floor thousands of feet below its surface. Scientists thought life would be impossible in the searingly hot temperatures (400°C, 750°F), oppressively high pressures (thousands of pounds per square inch), complete darkness, and toxic chemical brew typical near these ocean-floor vents. In place of sunlight, microbes living there use chemical reactions involving hydrogen sulfide, common in the enriched seawater pouring out of the vent, to generate energy. Other creatures survive by eating the microbes, or each other.

Researchers have also found bacteria in small pockets of liquid water embedded twelve feet deep in "solid" lake ice in the McMurdo Dry Valleys of Antarctica. The liquid water needed to support life is provided when the Sun heats small amounts of dirt embedded in the ice, causing the surrounding ice to melt. The dirt also provides chemical nutrients for the bacteria that photosynthesize, grow, and reproduce in the liquid water pockets during the long Antarctic summer days.

The Rio Tinto in southwestern Spain is another interesting environment for life. The river has a deep red color, like red wine, because of iron dissolved in the water. It is highly acidic, with a pH of 2.0 in most of the river (only slightly less acidic than sulfuric acid). Microbes living in the water also use the iron and sulfur minerals for chemical reactions that generate energy. Metabolic products from these reactions contribute to the low pH of the river. Numerous algae and fungi also thrive here.

Perhaps most surprising, scientists have discovered bacteria living in rock buried 1.5 kilometers (nearly a mile) underground in an area known as the Columbia River Basalt in the state of Washington. The bacteria survive in small holes and cracks in the rock that fill with water from underground aquifers. They live in complete darkness, at temperatures that approach 40°C (100°F) because of heat generated in the Earth's core. The groundwater reacts chemically with minerals like olivine and pyroxene in the rock to create hydrogen. The bacteria use this hydrogen for energy, and dissolved carbon dioxide for cell material, and make methane and other hydrocarbons. In essence, the bacteria live on nothing but the rock and water.

Extreme environments…on other planets?

The more we learn about the other planets in our solar system, the more we see how unique each one is, and what kind of environments each could have provided (or is currently providing!) to life as we know it. Three names, however, stand out in the minds of astrobiologists when they think about actively searching for life elsewhere: Mars, Europa (a moon of Jupiter), and Titan (a moon of Saturn).

Mars today is a frozen, dry world. Its predominantly carbon dioxide atmosphere is too thin to support liquid water on its surface, and its surface temperatures are too cold, averaging -65°C (-85°F). Yet its surface is covered

with winding channels that resemble ancient riverbeds, and there is water ice frozen in the planet's polar ice caps and subsurface permafrost. Enormous extinct volcanoes indicate Mars was once tectonically active, even though its core is now too cold to support volcanic activity. These geological observations, combined with the data coming back from the Mars Exploration Rovers (*marsrovers.jpl.nasa.gov/home*) indicate Mars once may have had a thicker, warmer atmosphere and liquid water standing and flowing on its surface.

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Could life have emerged at that time? Did it find a way to adapt, evolve, and survive the shift from moderate to extreme conditions? The frozen deserts of Antarctica resemble the Mars of today. If life can persist deep in the ice and underground rocks on Earth, perhaps it survives in the permafrost or polar ice caps of Mars.

Europa, a moon of Jupiter that is slightly smaller than Earth's Moon, is thought to have a liquid water ocean, believed to be between 50 and 100 kilometers deep. The ocean surrounds Europa's rocky interior, and is covered by a layer of water ice a few kilometers thick. Cracks and streaks crisscross Europa's surface. Scientists think the cracks were created by the gravitational twisting of the ice sheet and that the streaks are visible water that has seeped up through the cracks.

A curious analogue to Europa's ice-covered ocean can be found in Antarctica. In 1996, scientists discovered evidence of a lake of liquid water deep underneath the ice at Russia's Vostok Station about 1,000 kilometers (620 miles) from the South Pole. Dubbed Lake Vostok, the liquid water sits under about 3,710 meters (12,169 feet) of ice and may have been isolated for 500,000 to a million years. No one knows if there is any kind of life in Lake Vostok. So far, scientists have not drilled into the lake's water, because organisms carried in the drilling equipment can contaminate the lake. Contamination by Earthly organisms is a concern for researchers who want to look for evidence of life on Mars and in Europa's ocean, too. Techniques for drilling without contamination will prove invaluable when landers and subsurface probes are sent to explore Europa and Mars.

Titan, Saturn's biggest moon, is the only moon in the solar system with a thick atmosphere. Methane clouds float close to the surface. A thick smog of organic molecules, about 300 kilometers (186 miles) above the ground, and a thin haze high in the outer atmosphere complete the picture. These clouds and haze keep nearly all sunlight from reaching Titan's surface, which remains at -180°C (-290°F). While too cold for liquid water, scientists speculate that Titan may have lakes or oceans of liquid hydrocarbons like methane and ethane, a constituent of natural gas here on Earth. Large rocky landmasses, rather like continents, may rise out of the "oceans" on Titan's surface. Conditions on Titan may resemble those on Earth when life first began, which is one reason astrobiologists find this moon of Saturn so intriguing. The Cassini mission, a joint effort of NASA, the European Space Agency, and the Italian Space Agency, entered into Saturn's orbit on June 30, 2004, and will deploy the Huygens probe to Titan in December 2004. Huygens will enter the murky atmosphere of Titan, and eventually descend via parachute onto its mysterious surface, collecting data all the way.

The poster in your classroom

The poster has a threefold approach to addressing the questions of astrobiology: What is life? Where is it? How do we find it? (1) It can be used as a visual tool. Students will see the link between Earthly extreme environments and solar system bodies just by looking at it. (2) The back of the poster contains an extended background science reading for the teacher, regardless of the science discipline(s) taught. This narrative is meant both as a professional development experience for the teacher, as well as a source of information supporting the activities. Finally, as mentioned, (3) there are three standards- and inquiry-based classroom activities. They were field tested by middle and high school teachers and found to be usable within a variety of subjects, from biology to chemistry to astronomy. The activities can be used separately or in conjunction. Activity one is on the back of the poster in its entirety. All three activities, as well as an extended background reading and other supporting resources, can be found at *nai.arc.nasa.gov/poster*. ■

NSTA Connection

To learn more about the ancient bacterial domain Archaea, NSTA members can read The Once and Future Bacteria, available at *www.nsta.org/sciconnect*.

About the NASA Astrobiology Institute

The NAI is composed of 16 research teams distributed around the country; each with its own Education lead. Many professional development programs in astrobiology for teachers are coordinated regionally and nationally. Visit *nai.arc.nasa.gov/teachers* to get involved.