

## New hope for life beyond earth.

by Paul Davies

**In the early 1970's, the research submarine, Alvin explored a system of volcanic vents on the floor of the Pacific Ocean and biologists were surprised to see a variety of organisms living near the vents in total darkness and at enormous pressures thereby hinting that life on Earth is not restricted to the near surface only. The discovery that microbes dwell deep in apparently solid rock gives credence to the theory that life can be transported between planets inside material blasted into space by big impacts.**

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As scientists discover bacteria thriving in ever more extreme environments, the prospects of finding life elsewhere in the solar system become ever more intriguing.

IMAGINE A VISITOR FROM SPACE going into orbit about planet Earth and observing its surface. There would be abundant evidence that our planet is swarming with life: atmospheric oxygen produced by plants and algae, chlorophyll in the spectrum, changing patterns of vegetation, and the conspicuous effects of human activity. What would be less obvious, even with sophisticated equipment, is that the biosphere extends deep beneath the surface. Indeed, according to some scientists, there may be as much biomass lurking inside our planet as there is atop it.

Belief in some sort of inhabited underworld is as old as human culture and remains an abiding myth even today. It has proved the stimulus to science fiction stories from Jules Verne's classic *Journey to the Center of the Earth* to Robin Cook's recent novel *Abduction*. Alas, the reality is more prosaic than the fantasy. There are no monsters lurking in vast cavernous spaces, no hidden civilizations--just microbes dwelling in tiny rock pores. Yet the existence of these real-life denizens of the underworld has far-reaching scientific consequences and is transforming the prospects for finding life on other bodies in our solar system and beyond.

### LIFE BELOW EARTH

The first hint that life on Earth is not restricted to the near surface came in the early 1970s when the research submarine Alvin explored a system of volcanic vents on the floor of the Pacific Ocean. Biologists were amazed to see a variety of organisms living near the vents, in total darkness, and at enormous pressures. These creatures included weird varieties of crabs, clams, and tubeworms. Stranger still, Alvin discovered colonies of microbes living off the scalding effluent that spews from the vents. These

hardy organisms are known as hyperthermophiles because of their extraordinary heat tolerance. Some thrive in temperatures above the normal boiling point of water. (Because of the high pressure, water at that depth doesn't boil at 100[degrees]C.) Furthermore, since sunlight cannot penetrate to the bottom of the ocean, photosynthesis isn't possible. Instead, these primary producers use thermal and chemical energy to survive.

If subsurface life were restricted to pockets surrounding volcanic vents on the seabed, it would be little more than an exotic curiosity. But Alvin's discovery turned out to be just the tip of the iceberg. A few years later Cornell astrophysicist Thomas Gold, best known for his pioneering work on pulsars, persuaded the Swedish government to back a controversial drilling project. Gold had a theory that gas and oil might be sheltered beneath slabs of granite. While that idea remains highly contentious, the borehole drilled in the remote forests of Sweden did turn up something important: traces of organisms living several kilometers deep in the Earth's crust.

At first Gold's claim to have found signs of life so far underground was greeted with skepticism and even outright hostility. Colleagues were openly scornful, and Gold had trouble getting his results published. But by the mid-1990s several other research groups were finding microbes a kilometer or so deep too. In particular, boreholes drilled in the Columbia River region of Washington yielded a rich harvest of organisms, some of which were extracted and cultured in the laboratory.

About the same time, the International Ocean Drilling Project was recovering rock samples from nearly a kilometer beneath the seabed that were literally seething with microbes. It began to seem as if microbial life pervades the Earth's subsurface to a depth of some kilometers. Because temperature rises with depth due to Earth's internal heat, these deep-living organisms are also mostly thermophiles or hyperthermophiles. While it is too soon to say how extensive this deep, hot biosphere may be, it is clearly widespread, and its existence must be factored into the story of life.

Gene sequencing has enabled microbiologists to position these subterranean microbes on the tree of life.

## New hope for life beyond earth.

Significantly, the oldest and deepest branches of the tree are occupied by hyperthermophiles. The heat-loving subsurface organisms are living fossils, representing an extremely ancient lineage. They continue a lifestyle that may have remained largely unchanged for billions of years.

Some scientists see this as a pointer to how life began, suggesting that the first organisms dwelt in the hot, deep subsurface, where they were protected from the intense cometary and asteroidal bombardment that pounded the planets until about 3.8 billion years ago. The largest impacts would have released enough energy to swathe the Earth in incandescent rock vapor, boiling the oceans and sending a sterilizing heat pulse into the crust to a depth of at least a kilometer. Yet there would have existed a "Goldilocks zone" for hyperthermophiles in the crust of the ancient Earth, deep enough to avoid incineration by cosmic impacts, but not so deep that the geothermal heat would prove lethal.

An important question for astrobiologists is whether subsurface ecosystems can be fully self-sustaining. Many deep-living microbes depend indirectly on surface life, either feeding on organic molecules that descend from above or requiring traces of photosynthetically produced oxygen to metabolize. However, some microbes, called chemotrophs, are known to survive on inorganic gases and minerals without any assistance from the products of surface life.

For example, when water permeates hot rocks deep underground, it can become dissociated into hydrogen and oxygen. The dissolved hydrogen, together with carbon dioxide, can serve as an energy source for metabolism, and some microbes can utilize these chemicals by converting them into methane gas. In theory, such "methanogens" could support an independent food chain, enabling a subsurface ecosystem to endure in the absence of any surface life at all.

As long as scientists believed that biology required sunlight as well as liquid water, the prospects for finding life beyond Earth were severely limited. But with the discovery of subsurface life flourishing on Earth, the possibilities for life elsewhere are greatly enhanced.

### LIFE BEYOND EARTH

Take Europa, a moon of Jupiter. Space probes show a body completely covered with a thick layer of ice. But Europa has an internal heat supply, in the form of tidal friction. As Europa orbits the giant planet, it bends and flexes due to the continuously changing gravitational tug of war between it, its sister moons, and Jupiter. This flexing

produces a steady heat source capable of melting water ice in the interior of the moon. Indeed, observations suggest that beneath Europa's icy crust there is a substantial liquid water ocean. Photosynthetic life is ruled out below the ice because of the complete lack of sunlight--but chemotrophic life may still be possible. Opinions differ about how far European life might have evolved. Probably it would be confined to microbes clustering around hot vents on the ocean floor. Yet some optimists have painted a picture of rich marine life swimming in the pitch-black subsurface sea.

The realistic prospects for finding life beneath Europa's icy crust, or in the proposed underground saltwater oceans of Ganymede and Callisto, remain uncertain until astronomers get a better sense of what the Jovian moons are made of, how they formed and evolved, and what their radiation and space-weathering environments truly are. These questions are the driving force behind NASA's proposed Jupiter Icy Moons Orbiter (JIMO). This nuclear-powered craft, slated to launch no earlier than 2011, will use ion-propulsion engines to visit the three moons in turn, paving the way for eventual Jovian-system landers in the distant future.

The knowledge of organisms deep below ground has also given added hope to the chances of finding traces of life on Mars. In the first few hundred million years of the solar system, Mars was probably more hospitable to life than Earth. Its main advantage concerns its rate of cooling. All the planets started out intensely hot, but Earth was doubly afflicted. As our planet was first cooling, a Mars-size body plowed into it, forming the Moon and melting Earth in the process. Despite constant bombardment by primordial solar-system flotsam and asteroid-belt strays, the smaller red planet had the chance to cool before Earth, opening up an earlier opportunity for subsurface life. Comfortably ensconced beneath a kilometer or two of rock, microbes on early Mars could have withstood the worst of the bombardment and thrived at a time when Earth's crust was still lethally hot.

Later, life may have been possible on the Martian surface. Evidence from spacecraft suggests a warm, wet Martian epoch. Some even speculate that Mars once had enough water to cover the planet with a 1-km-deep ocean (S&T: August 2003, page 30). The recent finding by the Opportunity rover proving that parts of Mars were indeed soaked with water (May issue, page 44) strongly backs up that claim.

Once the intense bombardment abated, near-surface and even surface life may have evolved on Mars, taking advantage of meandering rivers, volcanic vents in shallow lakes, and gurgling springs on the sides of volcanoes. All

## New hope for life beyond earth.

this came to an end when the atmosphere leaked away, sending the surface temperature plummeting and transforming an ancient paradise into the freeze-dried desert we see today.

The prospects for finding any sort of extant life on Mars are slim but perhaps not totally hopeless. From what we know about terrestrial life in extreme environments, one should not completely rule out some sort of hardy microbial subsurface life on Mars. Estimates of the Martian heat flow suggest that the planet's internal temperature is sufficient to melt the permafrost a kilometer or two below the surface, creating some briny aquifers that could, in principle, host the sort of bacteria that lurk deep within Earth's crust. Candidates include methanogens, making a living from hydrogen or hydrogen sulphide and exuding methane gas as a byproduct. Britain's Beagle 2 lander, which formed part of the European Space Agency's Mars Express mission, was specifically designed to sniff out telltale traces of methane that might have percolated to the surface. With the loss of Beagle 2, we shall have to await future missions before testing this hypothesis further. If microbes are clinging on for survival below the Martian surface today, they might be a remnant of the earliest form of life there, or they could represent the last remaining vestiges of a once-flourishing surface biota, which retreated belowground and adapted to subsurface living when the red planet froze.

These developments also carry important implications for extrasolar life. Astrobiologists traditionally defined the "habitable zone" around stars as the distance at which an orbiting planet might sustain liquid water on its surface for extended durations. The conventional habitable zone around the Sun, for example, extends from somewhere between the orbits of Venus and Earth out about as far as Mars. The precise extent of a habitable zone depends on the mass of the star, where it is in its evolutionary cycle, and assumptions about planetary atmospheres.

Subsurface life implies that planetary systems may possess more than one habitable zone. Giant planets are likely to have moons, like Europa, large enough to undergo significant tidal friction, elevating the temperature above the freezing point of water even when they are located far from the star. Indeed, it is possible to contemplate moons with subsurface life orbiting rogue giant planets that have been flung out of their planetary systems or born as orphans and left to wander the dark interstellar spaces (S&T: November 2002, page 38).

### LIFE IN TRANSIT

The discovery that microbes dwell happily deep in apparently solid rock gives credence to the theory that life

can be transported between planets inside material blasted into space by big impacts. Although the intense early bombardment finished long ago, Mars and Earth still take a big hit from time to time. Every few million years, one of these impacts will pack enough punch to splatter debris through interplanetary space. Calculations by H. Jay Melosh and his colleagues at the University of Arizona indicate that a substantial fraction of the ejected material avoids being excessively shock-heated or pulverized and could convey live microbes into space.

Cocooned inside a boulder a couple of meters across, a microbial colony could withstand thousands or even millions of years in orbit. Crucially, any radiation would be drastically reduced by the rock's shielding effect. The incumbent organisms would also be spared incineration if the rock were to plunge through the atmosphere of another planet. The cold vacuum of space would oblige the microbes to cease metabolizing, but it would also act as an excellent preservative. We know that Mars and Earth trade rocks on an ongoing basis; it seems likely that they would trade organisms too, if there is--or was--any life on Mars. Similar "transpermic" processes might be expected to operate between nearby planets elsewhere in the universe too, though the chances of an exchange of life between neighboring star systems in this manner are extremely slim.

The origin of life remains a tantalizing mystery. Did the very first organism form in the broiling bosom of the Earth or in the less torrid depths of ancient Mars? Or was it incubated in an entirely different setting--in a balmy, sun-drenched lake, perhaps, during a lucky quiescent interregnum of the bombardment--multiplying and spreading to the deep subsurface only later? Does the genetic record of a hot, deep past indicate a hot, deep origin, or just a genetic bottleneck through which the primeval biosphere was squeezed by later violent impacts?

The answers to these questions will not be forthcoming without a continued effort to search for extreme life on Earth, Mars, and beyond. President George W. Bush's dramatic announcement in January of a future manned mission to Mars will give added impetus to NASA's flourishing astrobiology program. After all, solving the riddle of life's origin --one of the biggest of the big questions of existence--is a central motivation for exploring the solar system. On the way, we may determine whether the cradle of life was akin to the biblical Garden of Eden, or whether life was forged in a location closer to the traditional concept of Hell.

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## New hope for life beyond earth.

recent book, *The Fifth Miracle: The Search for the Origin and Meaning of Life*, is published by Simon & Schuster.