Life’s undersea beginnings
Scattered across the dark, wet desert of the ocean floor lie teeming oases centered on volcanic hot springs. The spring waters carry chemicals that support a bizarre group of organisms far from the reach of the Sun’s energy. Could life have originated in this environment?

by Joseph Cone
On February 19, 1977, marine geologist Jack Corliss saw something no one had ever seen before.

Five hundred miles off the coast of Ecuador, Corliss and two colleagues descended to the Pacific Ocean floor in the research submersible _Alvin_. Two miles below the sea surface, the sub’s lights were turned on, and a perpetually dark world sprang into view. A silvery sheen of water seemed to shimmer out of the rocky floor.

Corliss was elated. As the leader of the expedition, the Oregon State University researcher realized that the shimmering water meant the years of work that had preceded this dive were paying off richly. Warm water was coming out of the seafloor and mixing with the cold surrounding water. For the first time anywhere, humans were seeing active hot springs on the ocean floor. The expedition was already a success.

But Corliss looked beyond the veil of hot water. As he stared through it, there, in the normally frigid, barren depths of the sea, he saw an oasis of animals. And what animals they were: shoe-sized giant clams, pink rat-tailed fish and, most extraordinary of all, enormous upright things — worms, they looked like, with white outer tubes and red protruding tips, like giant lipsticks.

Over the next hours, days, and months, the thoughtful questions would be framed. Why were all these animals thriving there, at the dark bottom of the sea? How were they surviving? But as Corliss sat cramped inside the tiny research sub, straining for a view out the window, he wasn’t thinking yet. He was still looking in wonder. He always believed that it was important to be open to the universe, that it would then reveal itself; now that was happening. He knew the animals held powerful secrets. What those might be exactly, he did not know.

As Corliss discussed his discovery with other scientists, one idea kept coming up: Seafloor hot springs, with their abundance of hot chemical-laden water, resembled Earth’s earliest ecosystem more than any other environment still existing. Astonishing as that idea was, Corliss went further. Hot springs, he began to suspect, didn’t just resemble early ecosystems. They were the very settings in which life on Earth began. He was convinced of it. Now he wanted to know how it happened. His curiosity set him on perhaps the most compelling intellectual quest in the life sciences, the search for the origin of life.

Today, the idea that life on Earth started at seafloor hot springs has emerged as a recognized contender for the explanation to this oldest riddle. One sign: the scientific journal, _Origins of Life and Evolution of the Biosphere_, devoted an extraordinary 200-page issue to the topic in 1992, with articles by American, European and Asian scientists. But in 1977, Jack Corliss was the one scientist who devoted himself full-time to the idea.

Colleagues talk about him as an affable, imaginative guy, always happy to explore an interesting idea. But Corliss was also able to focus intensely on difficult problems, to push at them until they yielded to him.

He earned his doctorate from Scripps Institution of Oceanography during the 1960s, when plate tectonics was emerging as the new description of the way the Earth works. From early on Corliss recognized

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A “black smoker” hot spring near the East Pacific Rise off Acapulco, Mexico, emits sulfide-laden water at 650 degrees F.
that moving plates might cause hot springs to erupt on the seafloor. It followed naturally: If the ocean crust was moving apart along seafloor ridges, water would sink down in cracks in the crust and become heated in the subfloor and emerge again as hot springs. Corliss’ Ph.D. work involved chemical studies of seafloor rocks, which supported the existence of the still undiscovered hot springs and ultimately led to his involvement in the 1977 expedition to the Galapagos Islands off Ecuador.

After the expedition’s success, Corliss turned increasingly from the geology of the hot springs to the question of the origin of life. His thinking got a big boost from a colleague at Oregon State, John Baross. Corliss gave Baross, a microbiologist, water samples obtained on the Galapagos cruise. From these Baross cultured microorganisms that had been living in the water. What he found was another surprise. The microorganisms used sulfur compounds of the hot springs as an energy source. Unlike virtually all other life on Earth, they were neither directly nor indirectly dependent on photosynthesis; instead they fed on chemicals. The process, known as chemosynthesis, explained how the organisms of the hot springs were surviving far away from the light of the sun. Baross recognized that as a life-support strategy, chemosynthesis was much simpler than photosynthesis and therefore likely arose first.

Baross and Corliss began talking about the origin of life in earnest. They agreed that they had enough elements of a plausible story to develop and write into a scientific article. They enlisted the assistance of Sarah Hoffman, a graduate student working with Corliss. Hoffman did most of the actual writing of the paper on which the three collaborated.

Since the 1950s the prevailing scientific opinion had been that life began in the sea. Two researchers at the University of Chicago, Stanley Miller and Harold Urey, had done famous laboratory experiments in which they made some of the building blocks of life from inorganic chemicals. They heated a closed flask filled with water, methane, ammonia and hydrogen; these were believed to be the primary components of the sea and atmosphere when life began. They boiled the water and shot an electric spark, imitating a lightning bolt, through the vapor. Among other things, the reaction produced two amino acids, the constituents of protein.

The assumption was widely made that given enough time, this “primordial soup” would cook up increasingly more complex molecules. Ultimately, living organisms would appear. The experimental results were reasonably easy to duplicate, and the general idea that life began in the early ocean gained currency. But many questions remained.

Corliss, Baross and Hoffman addressed two of these questions in 1980, in an ambitious article called “Submarine Hydrothermal Systems: A Probable Site for the Origin of Life.” Where in the sea did life begin? And how did non-life become life?

To support their proposal that the hot springs were the site where life began, the Oregon scientists needed to make a case that hot springs were ancient. Four billion years ago, they pointed out, the planet was already covered by a warm ocean, and it already had underwater volcanoes, which helped carry the
Hot rock deep underground causes seawater to loop through hot-springs, picking up heat and chemicals as it goes.

The leftover heat of Earth's formation to the planet's surface where it could radiate into space. Volcanic vents became the first submarine hot springs.

But the argument was only halfway there. Seafloor hot springs might have been common at the time life appeared but still not the actual site of life's genesis. To complete their argument, Corliss, Baross and Hoffman would have to show why life would be likely to form in the hot springs and not in some other ancient environment. And to do that, the researchers would have to consider just what the first living things were like — no easy challenge.

Although complex in its details, their 1980 plot was simple in outline. The chemical elements needed for life are present in the hot springs fluids. Earth's geothermal energy can make complex molecules out of those building blocks. The complex molecules weren't made all at once, but were assembled over time in different parts of the hot springs system.

The process began, the three researchers said, when the seafloor split open above subterranean bodies of hot rock. Seawater trickled down into these cracks, prying the rock apart at deeper layers as it descended. Eventually, the water reached the top of the hot rock. Here, the water might be heated to nearly 1,800 degrees F (1,000 C.) At such extremely high temperatures, the water would react with the rock, extracting basic ingredients needed to make organic molecules. These ingredients are carbon, nitrogen, oxygen, hydrogen and sulfur.

This chemically enriched, superheated seawater would cool and be transformed in successive steps as it returned to the surface through channels in the rock. First, amino acids would be formed at the highest temperatures. Then, as the water became comparatively cooler as it rose farther away from the heat, other organic molecules would form, ultimately sheathing the amino acids in a "protocell." This initial cell would grow in size, proliferate and undergo natural selection. In short, it would live and evolve.

This, they suggested, was how life began in the primordial soup.

The reception to the hot springs idea by the professional community was initially cool. The paper was rejected by Nature, the prominent journal. Another
scientific journal later published it, but still the idea seemed slow to catch fire. Corliss and Baross didn’t wait around for the rest of the scientific community, though.

For Baross, the avenue to understanding the origin continued in his laboratory, where he has grown cultures of hot-springs bacteria. In the early 1980s this work resulted in some of the most exciting, though controversial, findings in microbiology in recent times.

For his experiments, Baross used a specially made titanium syringe to transfer bacteria from holding flasks into a metal sphere known as a “pressure bomb.” The sphere was designed to imitate conditions on the seafloor, producing pressures of 500 atmospheres and temperatures of 930 degrees F (500 C). (The high pressures kept the water from boiling despite the heat.) In 1983, in collaboration with microbiologist Jody Deming, he published a paper in Nature saying they had grown bacteria at 480 degrees F (250 C). Life had never been detected before above about 200 degrees F (95 C). The world of biological research went into an uproar.

“Quite a number of people thought that our results just couldn’t have happened,” Baross muses. “People said it was a ridiculous experiment — that the bacteria just wouldn’t survive above 100 degrees C. It’d be like frying an egg in a pan,” they said. The protein would just break down.”

But Baross says that for a number of reasons he knew that the cultures had grown at 480 degrees. One of the reasons was that the amount of protein in the cultures increased in a way characteristic of bacterial growth.

Deming’s and Baross’ data, which argued that hot-springs bacteria lived on sulfur compounds and grew at high temperatures, supported Baross’ belief that the bacteria are of a very ancient lineage. Since the 1970s, microbiologists led by Carl Woese of

Some scientists say the simplest building blocks of life formed deep in hot springs. More complex units formed higher up.
the University of Illinois have been developing an evolutionary tree for bacteria, and they have consistently found sulfur-using and heat-loving bacteria to be ancient. In 1988, a computer model of the evolutionary tree developed by James Lake, a molecular biologist at the University of California at Los Angeles, supported the conclusion Woese and others were already leaning toward: that all bacteria and every other living thing evolved from a single-celled, sulfur-using organism, which probably lived in boiling sulfur springs.

If vent microbes turn out to be as ancient as his evidence suggests they are, Baross believes they may offer insights into the biochemical conditions under which life developed.

In the meantime, his laboratory — now at the University of Washington — has been looking at enzymes extracted from cultures of his high-temperature bacteria. This work has attracted a lot of interest from biotechnology companies because the enzymes and other molecules produced by the organisms are capable of functioning in high temperatures. The hotter a biochemical reaction runs, the faster it runs and the more marketable product is produced. Accordingly, biotech companies like to run their reactions as hot as they can, but molecules derived from low-temperature organisms often lose their most useful properties at high temperatures.

Baross now has over sixty cultured organisms from the hot springs, each a potential gold mine of industrial molecules. One of the leading manufacturers of biotech equipment, Stratagene, has contracted with Baross to provide them with promising bugs.

Corliss has taken a separate path in his pursuit of The Beginning. He left Oregon State in 1982 to devote himself full-time to the quest. He traveled to Europe. There he led the life of the itinerant scholar, visiting, meeting with and being influenced by some of the world leaders in theoretical physics and chemistry. Among them was Belgian physicist Ilya Prigogine, who first built a reputation with work on the thermodynamics of systems that exist far out of equilibrium. In 1977, he won a Nobel Prize for this work, but by then he was already beginning a second career shaking up the scientific establishment with other ideas. He became an early advocate of chaos theory, which is (to look at it one way) an ambitious generalization of non-equilibrium thermodynamics or (to look at it another way) an attempt to get inside the processes that cause the seemingly most erratic and unpredictable kinds of physical behavior in the universe — like life.

What Corliss learned from Prigogine was how natural systems can achieve order out of chaos. The necessary ingredient is the movement of energy from one physical location to another. Needless to say, hot springs possess that feature in abundance.

In his thinking and writing in the late 1980s, Corliss tried to apply this new physics in describing the precise steps that would occur in the hot springs in order to turn non-living matter into life. He used it to explain how, out of the jumble of organic molecules formed in the hot-
springs system, fragmentary nucleic acids and amino acids could emerge. Why would these molecules ever add up to anything more than chemical gunk? The gist of the explanation is that enough energy is moving through the system to keep it from collapsing into an equilibrium condition — one in which either nothing changes or things change slightly this way and that, but the changes never add up to anything.

When systems exist far from equilibrium, they often develop structures that help them dissipate some of their energy. This rather abstract principle applies to systems of all sorts. For example, if you upend a bottle full of water, the water will gug out irregularly and fairly slowly. But if you give the bottle a little swing as you overturn it, the water may form a vortex in the neck, in which case it will be able to flow smoothly and quickly. Sometimes a vortex may form spontaneously, as it does in a draining bathtub. The vortex is a structure appearing in the bottle or tub system that allows energy — the gravitational potential of the water — to dissipate. If a system is maintained out of equilibrium for a long period of time, it may retain its dissipative structure or even develop a more complicated one. Life, Corliss suggested, could have first arisen from such dissipative structures in undersea vent systems.

Since he was building conceptual models anyway, the next step for Corliss was to try his models out on that most powerful of modern modeling tools, the computer. And not just any computer. Starting in 1988, Corliss has been testing his hypothesis on one of the world's most sophisticated computers, the Massively Parallel Processor Array at NASA's Goddard Space Flight Center in Maryland.

With the MPPA Corliss wrote complex programs to simulate life's origins at the hot springs through the behavior of 250,000 separate processors. The model is not based on a detailed representation of DNA, RNA or protein. Instead, each processor represents a very simple and abstract unit that interacts with the others in very simple ways. The idea is to see just what it takes to get such elements to form themselves into structures that persist and perhaps even grow in complexity. According to Corliss, as long as there is energy flowing through the system, lifelike processes can appear spontaneously.

In 1993, Corliss turned to making videos to show (a little abstractly, of course) what the hot springs life-building process looked like. Later in the year, apparently satisfied that he had gone as far as he could for the moment, he took on another job, leading the group of scientists charged with revitalizing the scientific mission of the Biosphere 2 project in Arizona.

But even as Corliss moves toward the outer reaches of science in his investigations, more conservative researchers are beginning to pick up on his basic idea — that primordial hot springs could have provided a very congenial site for the beginnings of life. At an international series of professional meetings in the last several years, many researchers came forward to support the idea. Writing in the journal Origins of Life, Nils Holm of the University of Stockholm saw several reasons for this. First, most primitive organisms found today inhabit hot environments, including hot springs. Second, hydrothermal systems and deep sediments are among the few environments where primitive life would have been protected against meteorite impacts. And finally, hydrothermal vents are dynamic systems, possessing the flows of energy needed for pre-life geochemical processes.

One recent elaboration to the hot-springs idea has been advanced by geochemist Everett Shock of Washington University in St. Louis. Shock says scientists should devote more attention to hydrothermal vent sites away from seafloor ridge crests. He thinks hot springs on the ridge flanks, where venting is cooler and less violent and where it contains less oxygen, are more likely to hold clues to life's origin.

If the hot springs hypothesis is ultimately verified, the implications go far beyond planet Earth. It used to be thought that only a planet with a temperate surface and liquid water below the normal boiling point could support life.

"Consider other planets with the critical conditions of the Earth — hot on the inside, as Earth is with radioactive decay, and cool on the outside," Corliss says. "Underneath the ice on the moons of Jupiter, if there's a hot core, there will be a place with liquid water. It's interesting to imagine what we could do 500 years from now, landing on one of these moons, drilling down through the ice, putting a submarine below the ice and seeing what's there."

For Jack Corliss, such thoughts are a long way from staring at some rocks out the window of a submersible. But perhaps that's what happens when you're open to the universe.

Joseph Cone wrote Fire Under The Sea, an account of the discovery and exploration of seafloor hot springs. He is the science writer with Oregon Sea Grant, a research and education program at Oregon State University.