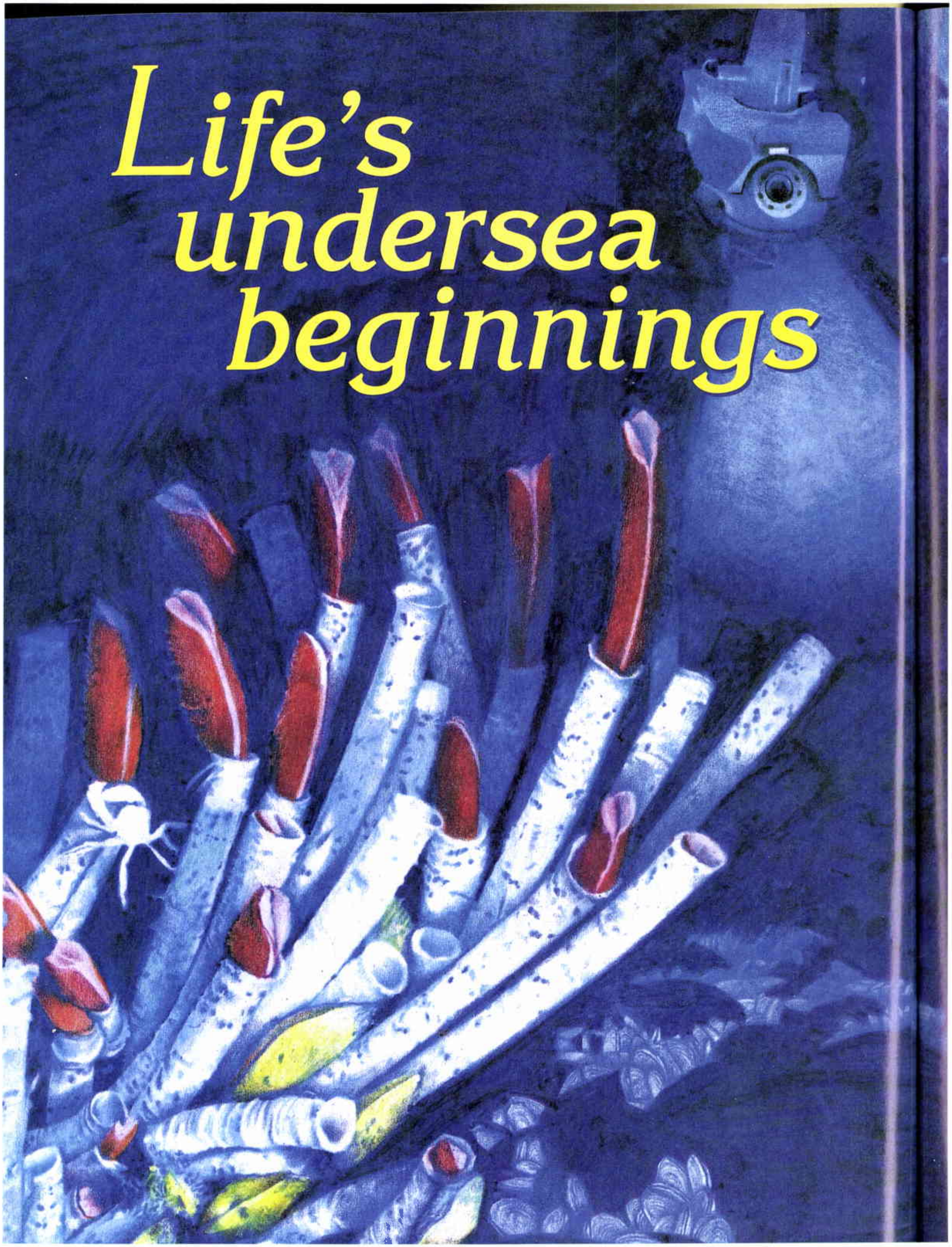
Life's undersea beginnings



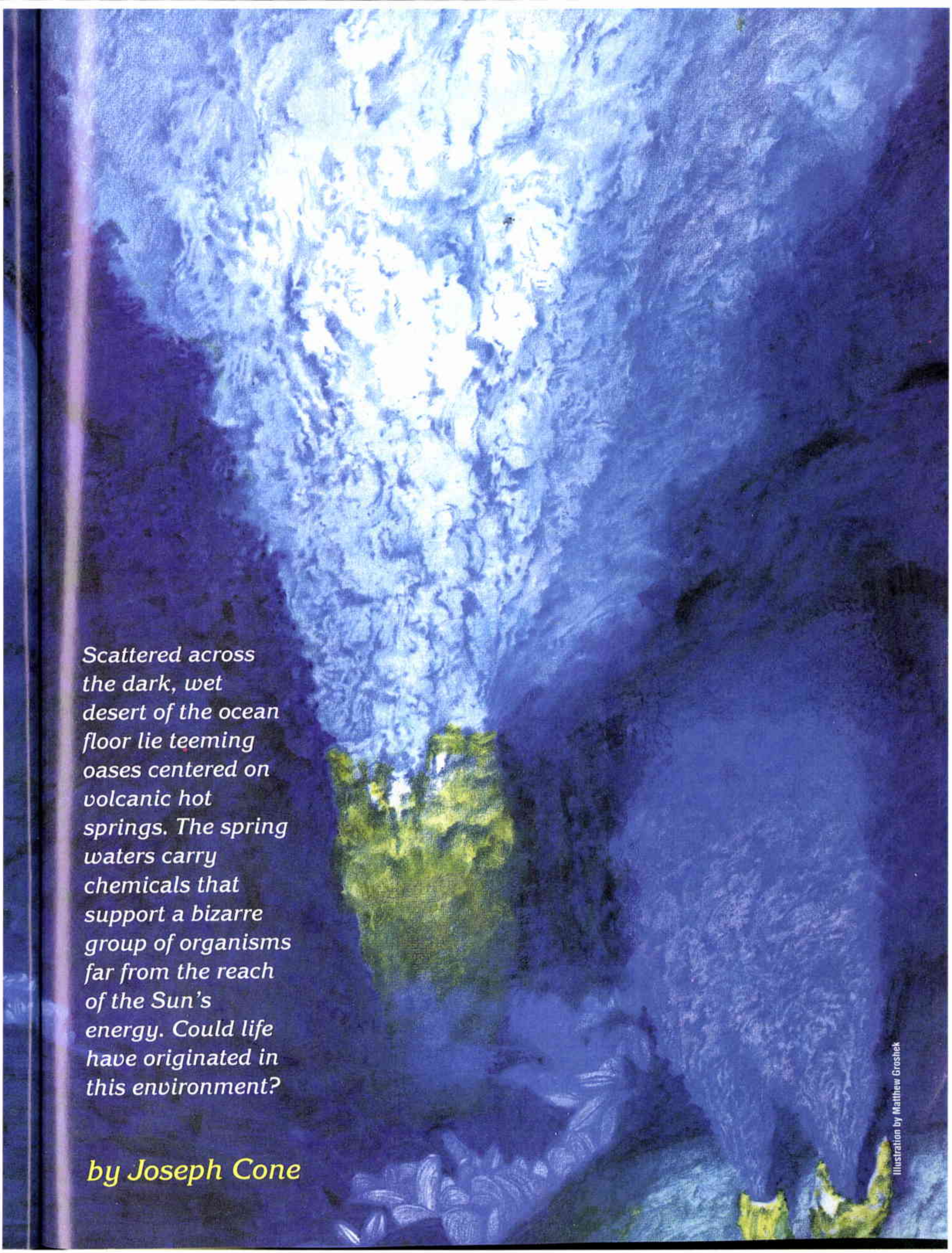


Illustration by Matthew Groshek

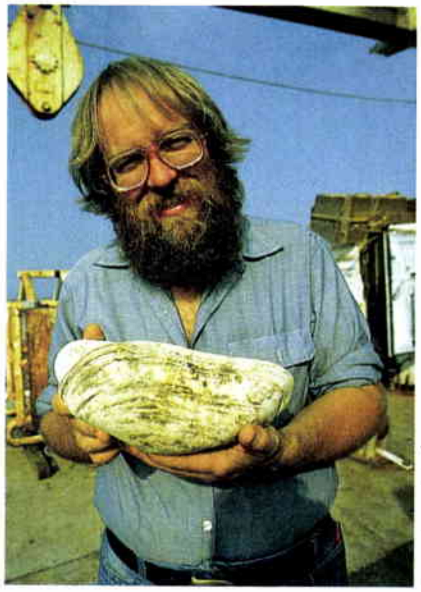
Scattered across the dark, wet desert of the ocean floor lie teeming oases centered on volcanic hot springs. The spring waters carry chemicals that support a bizarre group of organisms far from the reach of the Sun's energy. Could life have originated in this environment?

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.



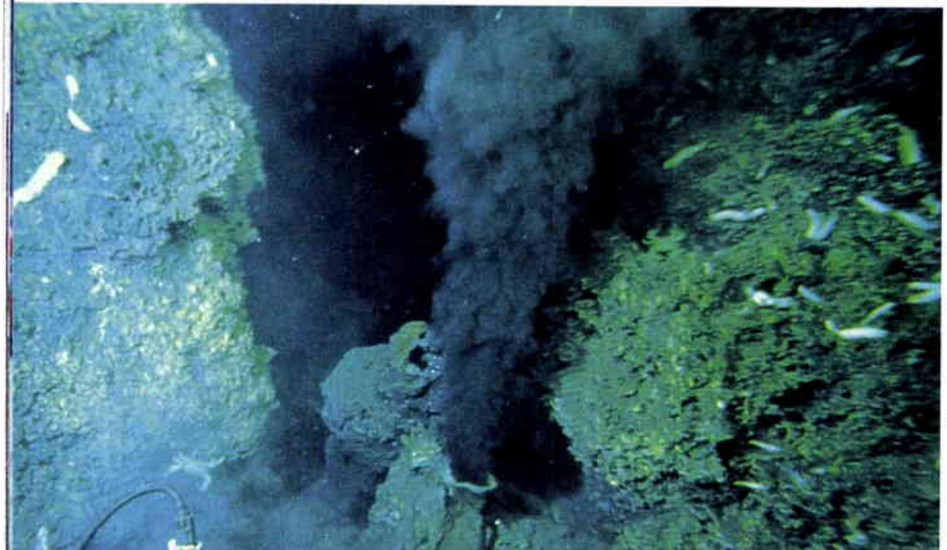
Emory Kristof/© National Geographic Society

Jack Corliss holds a newly discovered vent clam in the Galapagos Islands in 1979.

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.



Courtesy Dudley Foster/Woods Hole Oceanographic Institution

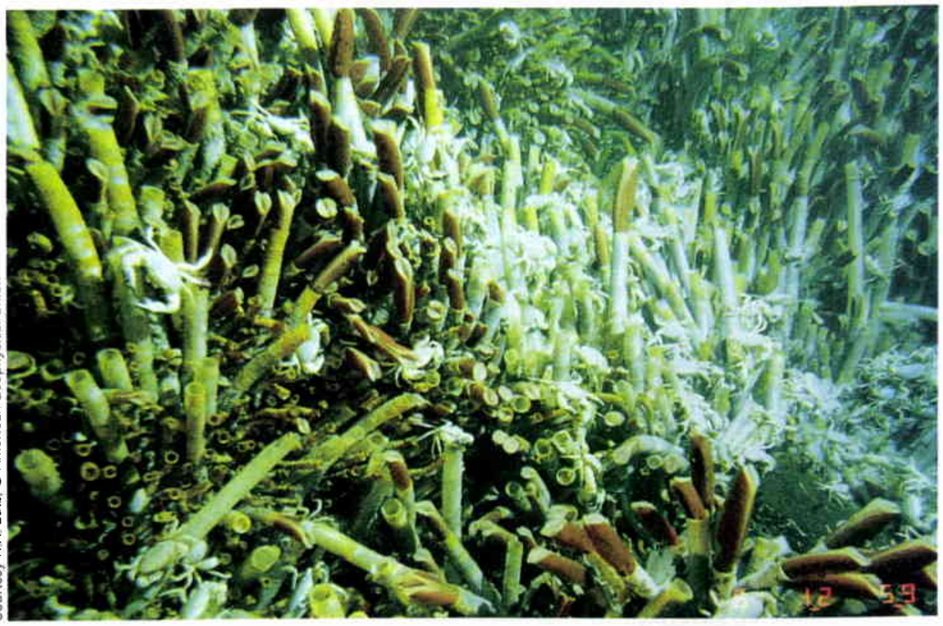
A "black smoker" hot spring near the East Pacific Rise off Acapulco, Mexico, emits sulfide-laden water at 650 degrees F.

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 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.



Courtesy R.A. Lutz, © American Geophysical Union

Two species of tube worm crowd the underwater hot spring called Genesis, located on the East Pacific Rise off Acapulco, Mexico.

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.

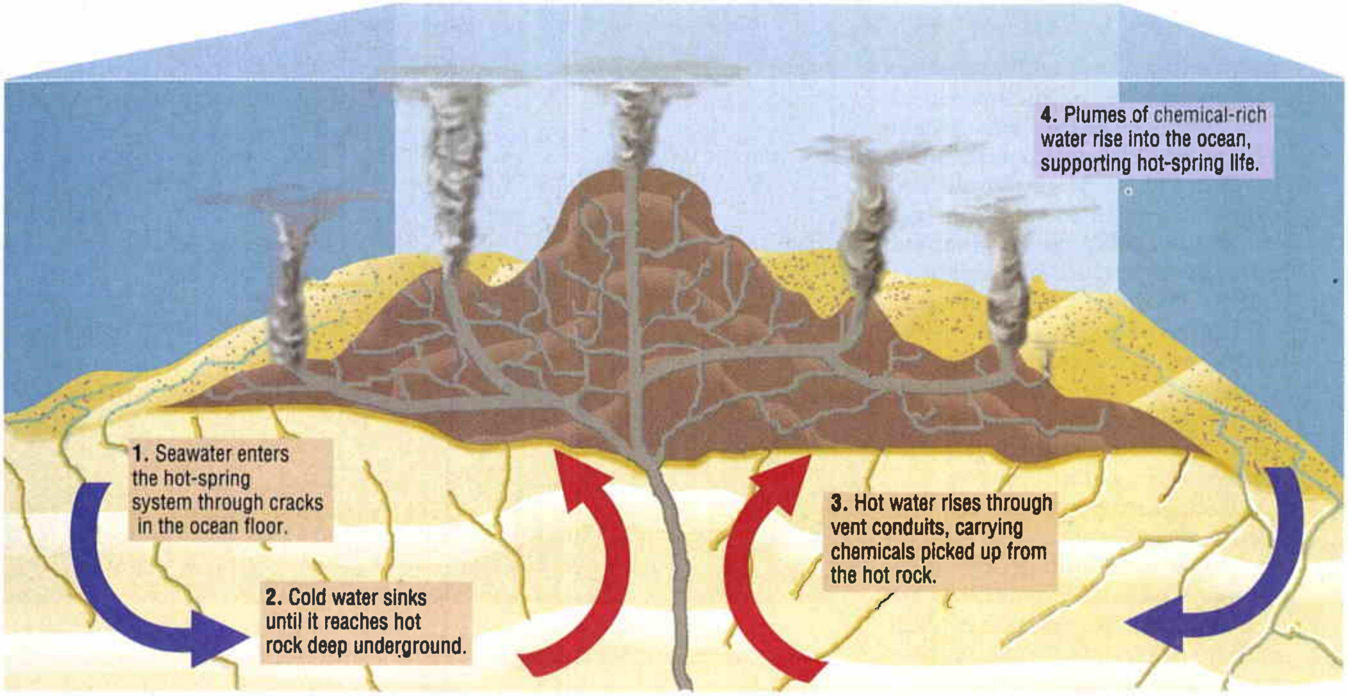
The assumption was widely made that given enough time, this "primordial soup" would cook up increasingly more complex molecules. Ultimately, living organisms would appear. The experimental results were reasonably easy to duplicate, and the general idea that life began in the early ocean gained currency.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

Courtesy William Chadwick/Oregon State University/NOAA

Researchers prepare Alvin for a dive aboard the research vessel Atlantis II, near the Juan de Fuca Ridge off Oregon.

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.

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

Crabs crawl among the tube worms and basalt at the Genesis hot spring site.