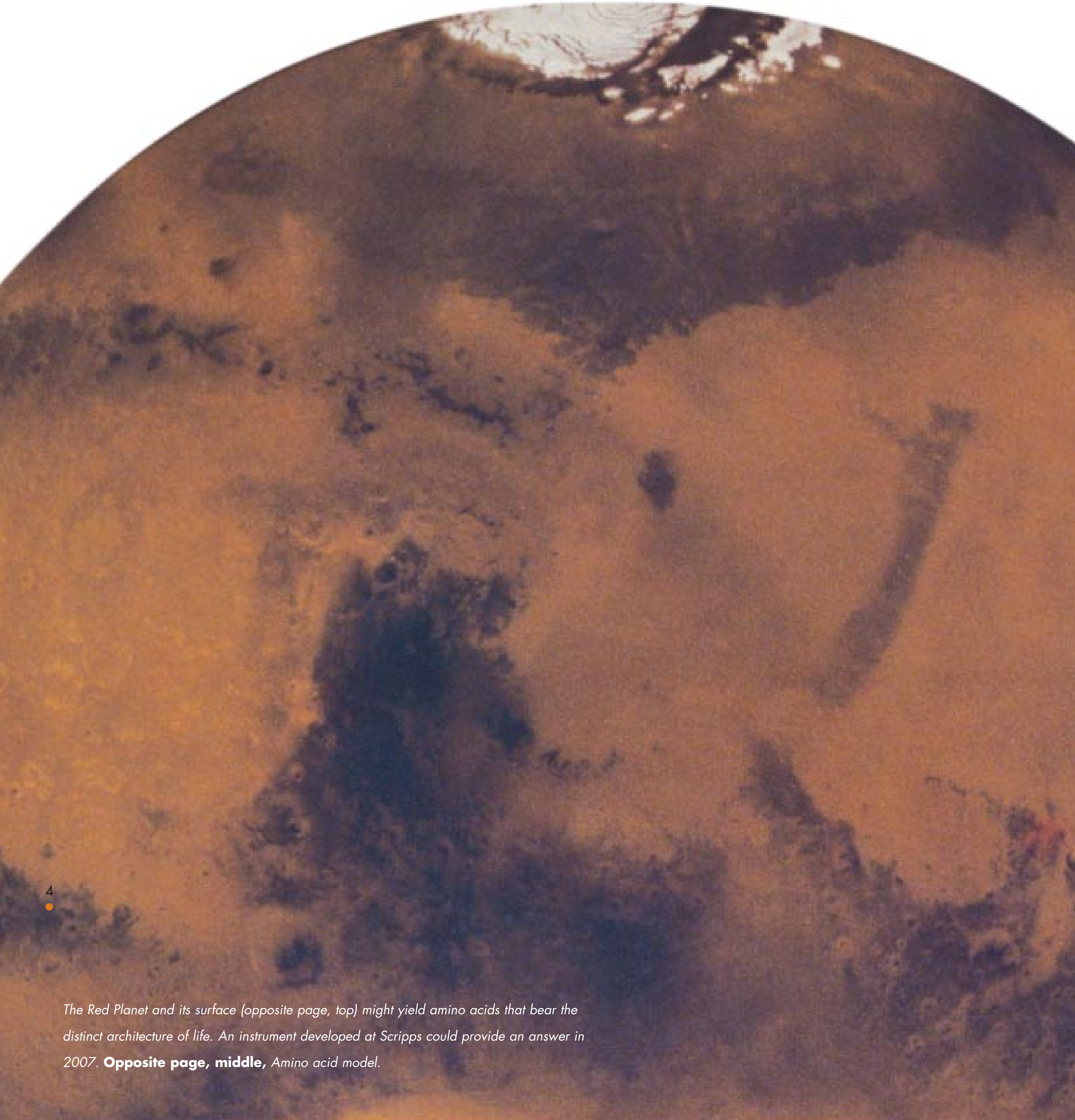
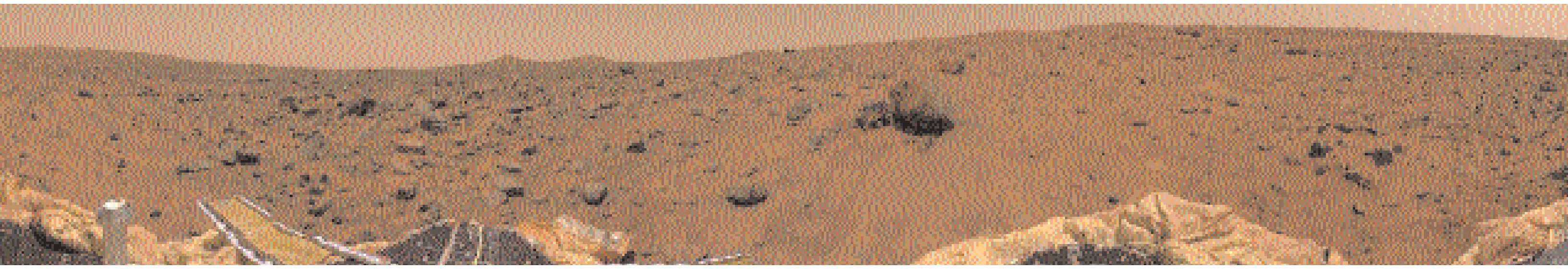
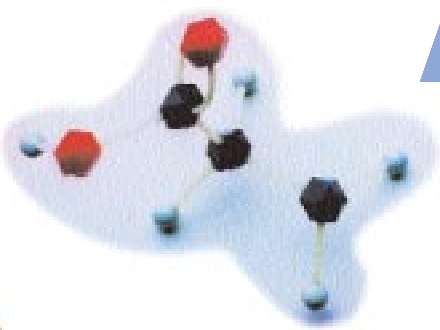
Organic Origins



The Red Planet and its surface (opposite page, top) might yield amino acids that bear the distinct architecture of life. An instrument developed at Scripps could provide an answer in 2007. **Opposite page, middle,** *Amino acid model.*



SEARCHING EARTH AND BEYOND FOR



BY ROBERT MONROE

An instrument born at Scripps could beam back to Earth the first real evidence of life elsewhere in the universe. If it survives an uncertain political climate at home and a harsh, inhospitable environment on Mars, a landing craft bearing this instrument—the Mars Organic Detector (MOD)—will touch down on the surface of the Red Planet after a September 2007 launch.

The palm-sized detector will "cook" spoon-sized amounts of Martian dirt and analyze the molecules that will be vaporized in its oven. It will search for amino acids, the molecules that join to form proteins and a key ingredient of life. If MOD finds amino acids, the analysis will continue in an effort to ascertain whether the acids are the kind that could only have been produced biologically.

Jeff Bada, a Scripps marine chemist and MOD's creator, has reason to believe the beamed-back answer will be a "yes." But before the life-on-Mars question is answered, Bada faces the more immediate consideration of an earthly matter: He hopes to keep alive the Scripps-based program called the NASA (National Aeronautics and Space Administration) Specialized Center of Research and Training in Exobiology (NSCORT).

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With RNA, the line between prebiotic matter and life blurs. Some scientists theorize that RNA molecules might have found each other in a vast, inhospitable prehistoric ocean to form life. How they could have met remains a mystery.

The term *exobiology* is only slightly older than the NSCORT program itself, coined in the late 1960s at a time when detection of extraterrestrial life seemed imminent to some individuals. The hope was not only to find life elsewhere but also to understand how it must have formed on Earth. Activity in the field hit an early peak in the mid-1970s when NASA's Viking spacecraft scanned the Martian surface. Surface samples of the red soil were taken, but no signals of the definite presence of life were found.

In the early 1990s came another surge of interest in Mars. Consequently, NASA began a different series of missions to the Red Planet. The series began with the unfortunate loss of the *Mars Observer* spacecraft in 1993, but rebounded four years later when *Mars Pathfinder* landed on the planet. At the same time, the space agency wanted to create academic ventures that would emphasize the education of a new generation of space scientists. Hence, the university-based NSCORT programs were created.

"NASA envisioned the need for more people in the relevant NASA science areas," said NSCORT investigator Gerald Joyce of The Scripps Research Institute, "so it created not just that training environment but that research environment, as well."

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Here, scientists have spent the past 10 years investigating the origins of life—whether on Earth, Mars, or elsewhere. The multidisciplinary program has been so successful, however, that NASA might fold it into a larger program.

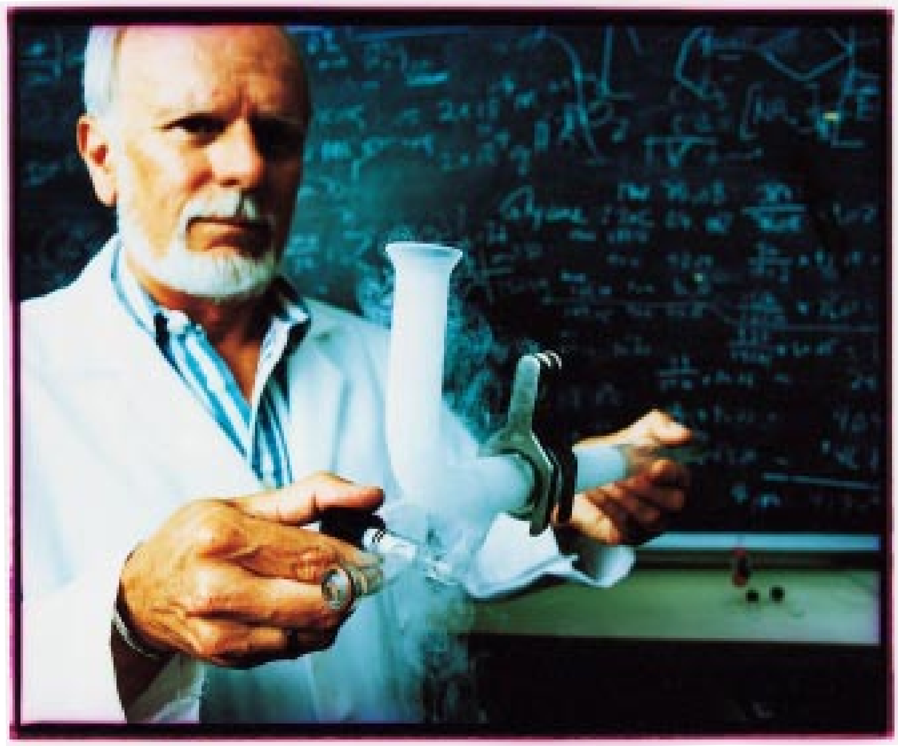
"NSCORT is such an important element in this discipline of biology," Bada said of the program he currently directs. "You want to keep something that works."

THE ORIGINS OF EXOBIOLOGY

Bada is a leader of one of NSCORT's laboratories and is part of a team of biologists and chemists who conduct research at the six NSCORT labs located at Scripps; the University of California, San Diego; the Salk Institute; and The Scripps Research Institute. Among these researchers are some of the pioneers of exobiology, a discipline defined as the study of the origin, evolution, and distribution of life in the universe.

Top, *Jeff Bada and students Oliver Botta (left) and Daniel Glavin in Bada's laboratory at Scripps.* **Bottom,** *Botta and Glavin separate and analyze amino acids in a high-performance liquid chromatograph.*

Right, *Jeff Bada and a prototype of MOD's sublimation oven that uses liquid nitrogen to cool material before analysis.*



NSCORT BY THE SEA

To the scientists who submitted a proposal to start an NSCORT in La Jolla, the chance for leading thinkers to collaborate in a well-funded environment was tantalizing. Scripps's participation in the program was a natural, although ocean and space sciences might seem as distant from one another as the distance between the ocean and outer space themselves. On the contrary, oceanographers at Scripps have been involved in space science almost since the beginning of the institution. (*See "Sailing in New and Old Oceans" on p. 12.*)

In addition, the search for the origins of life on Earth demands an intimate knowledge of marine chemistry and geology, the backbone of much Scripps research. For Bada, a scientist whose background is in organic chemistry, the connection between the ocean and the origins of life is a simple one: there would be no life here without the ocean.

In 1992, NASA accepted the proposal of the La Jolla scientists and the NSCORT program was launched. Its first director was Stanley L. Miller, who mentored Bada when the latter was a graduate chemistry student at UCSD.

The proposal approval meant nearly unbeatable access to grant money. NSCORT receives $960,000 a year and, because of its multicampus composition and emphasis on student training, is allowed to keep 72 percent of the monies to fund research. Consider that researchers must usually devote half or more of their grant money to university overhead costs.

"With five years of guaranteed support, you can do research that takes on answering the major questions," Bada said. "The block of five years is an incentive to take risks."

The researchers achieved early successes. Some of these accom-

Some exobiologists have theorized that comets such as Hyakutake helped seed early Earth with the ingredients for life. A vial containing a sample of a powdered Martian meteorite that has been analyzed for those ingredients.

plishments include finding what might be the earliest evidence of life on Earth, discovering the strongest evidence yet that comets seeded Earth with organic material needed for life to begin, and clarifying the point at which prebiotic matter crosses the threshold to become actual life.

Miller, for instance, has spent the past several years investigating what he believes to have been the first genetic material on Earth. His name also lends another kind of cachet to the team. Decades ago, Miller made a name for himself as one half of the famed Miller–Urey experiments. The research team coined the term "primordial soup," referring to the prehistoric muck from which life was believed to have arisen.

Miller's experiments in Harold Urey's laboratory at the University of Chicago in 1952 and 1953 gained worldwide attention with their conclusions about the beginnings of life on Earth. Miller synthesized amino acids in a glass chamber to simulate an environment that represented his best guess at Earth's early atmosphere. The world he simulated had what is known as a reducing atmosphere, one filled with methane, ammonia, hydrogen, and water vapor that could nurture the genesis of organic

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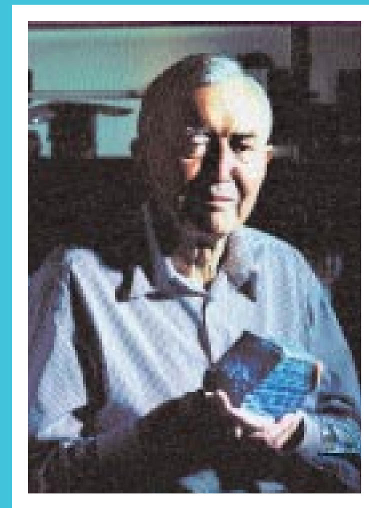
THE DATING GAME



Left, *Gustaf Arrhenius holds a sample of Greenland rock containing evidence of 3.8-billion-year-old life.* **Below,** *graduate student Mark van Zuilen*

HOW LONG DID IT TAKE for life to emerge after the formation of Earth? Scripps marine geochemist Gustaf Arrhenius helped narrow the inception window to a mere 800 million-year span.

Earth was formed about 4.6 billion years ago. Scientists generally have believed that because of the heavy bombardment of Earth by asteroid-like bodies, it took another billion or more years for the first life forms to appear. Because this life appears to have been biochemically advanced, the *very* first life forms must be even older, Arrhenius contended in his research during the mid-1990s. This work resulted in a claim that life emerged on Earth at a date of 3.8 billion years.

"We have 800 million years to play with," Arrhenius said. "Life must have either emerged on Earth or arrived on Earth in this time."

The 49-year veteran of Scripps set off controversy and a flurry of interest in 1996 when he and his graduate student Stephen Mojzsis reported that carbonate rocks obtained by colleagues in western Greenland contained trace amounts of deposits that seemed to have been produced by life even older than previously believed to have existed. At the time, scientists believed these carbonate rocks were of sedimentary origin.

Arrhenius had to back away from that initial claim, however. With student Mark van Zuilen and colleague Aivo Lepland, he concluded that the matter they had isolated was formed by hot crustal fluids impregnating the sedimentary rock much later in history. The false alarm led the team to develop verification methods that could prevent similar claims of early-life discoveries. Carbon comes in two stable varieties, or isotopes, bearing different numbers of neutrons in their atoms. Organisms concentrate the "lightest" carbon form with the fewest neutrons. The team is refining methods to distinguish this carbon from similarly light carbon produced by nonbiological sources.

New analysis of sedimentary rock has found measurable evidence of life dating back 3.8 billion years with no trace of meteorite bombardment or increase in space dust, revalidating Arrhenius's 1996 claim. Behind the revival were the verification methods developed by the Scripps team.

Minik Rosing, a researcher from the Geological Museum of Copenhagen, in collaboration with the Scripps team, verified the presence of biologically generated carbon in rock from the same area in Greenland in 1999. This time, the sample truly could be said to bear evidence of life 3.8 billion years old. It was also clearly of sedimentary origin.

In Rosing's dull gray-and-black-striped rocks lay an apparent record of early-life forms that either gained energy through photosynthesis on the surface of an ocean devoid of oxygen or lived as bottom dwellers, nurtured by the chemical energy from compounds released by seafloor vents. The remains of those creatures left minute freckles of organically produced carbon, which crystallized into graphite. The lack of impact features in the rock and the absence of interplanetary dust in it led Arrhenius to believe that Earth might not have been as heavily bombarded in the beginning as previously thought.

The methods of distinguishing biogenic from nonbiogenic carbon developed by van Zuilen and Lepland have helped support this new evidence and it has now gained widespread acceptance, Arrhenius said.

Left, *Housed in Jeff Bada's laboratory are numerous samples of comets and meteorites that could potentially provide researchers with the same sorts of amino acids as are produced biologically on Earth.*

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material when cooked into existence by concentrated energy from lightning strikes.

By the time NSCORT came into existence, however, evidence was emerging that Earth had a nonreducing or oxidizing atmosphere that breaks down organic material. Such an atmosphere would have consisted primarily of carbon dioxide. In these conditions, it would have been difficult to produce amino acids by a Miller–Urey-type synthesis.

SEASONING A THIN SOUP

Although Miller's assumptions regarding Earth's primitive atmosphere have been questioned, the Miller–Urey experiment changed how scientists approached the search for the origin of life. Exobiologists still believe that amino acids were a necessary element of the prebiotic world. There might have been a primordial soup of sorts, but it likely would have been an extremely thin broth. There probably was a much more sparse supply of these organic materials than originally thought, and even their presence would not make a life form.

"It was thought that proteins and amino acids were the initial building blocks holding the key to the origin of life, but it's not enough to have just proteins and peptides," said Gustaf Arrhenius, a marine geochemist at Scripps and leader of one of the NSCORT labs. "You have to have something to inform them." *(For more information on Arrhenius, see "The Dating Game" on page 9.)*

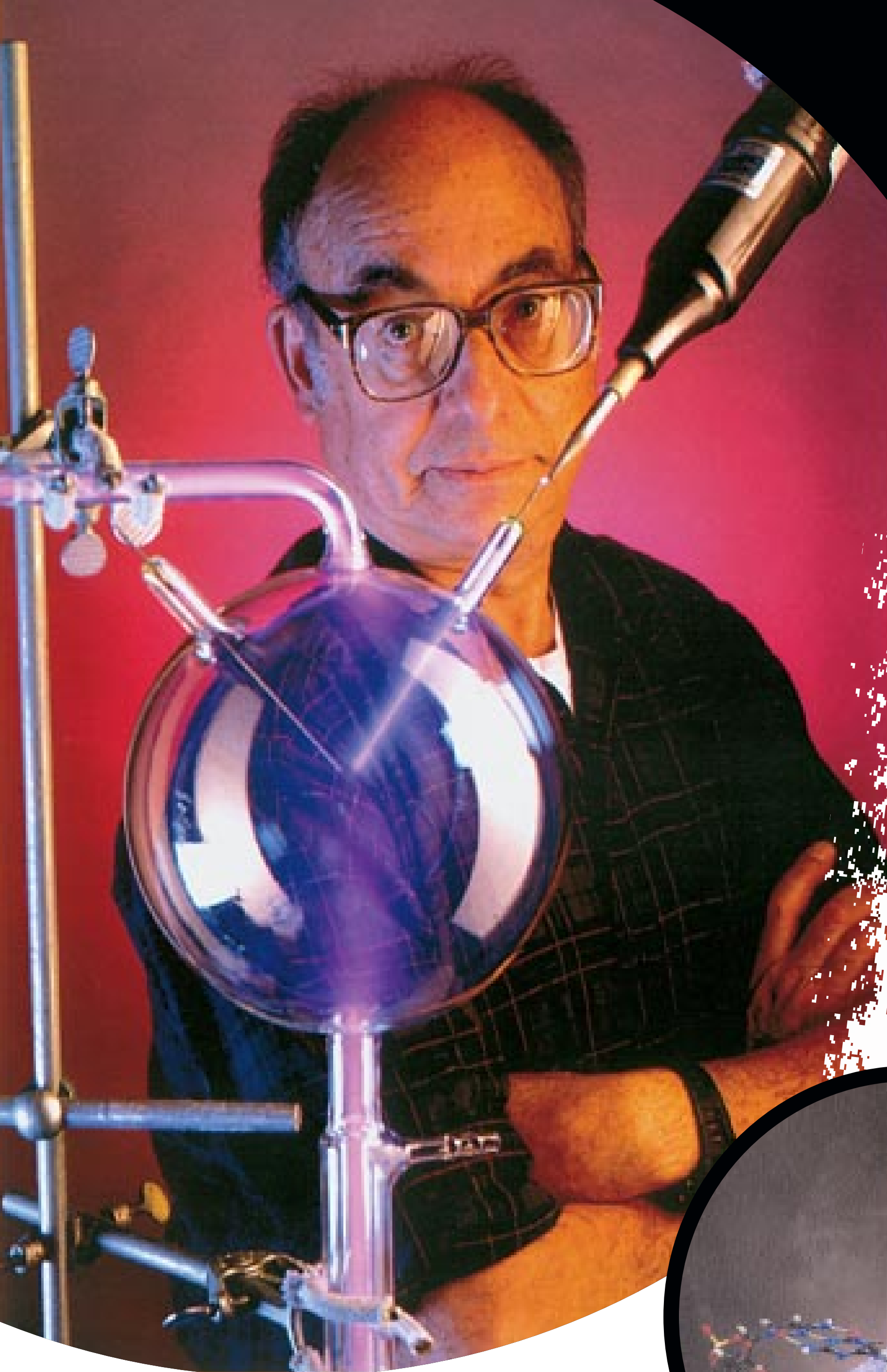
In other words, before it can be called "life," organic material needs instructions in the form of genetic information in order to know how to develop. Amino acids and proteins don't have that capacity but ribonucleic acid, or RNA, does. Most researchers now agree that RNA was one of the earliest life forms, once the sole viable inhabitant in the so-called "RNA World" that may have existed on Earth around 4 billion years ago.

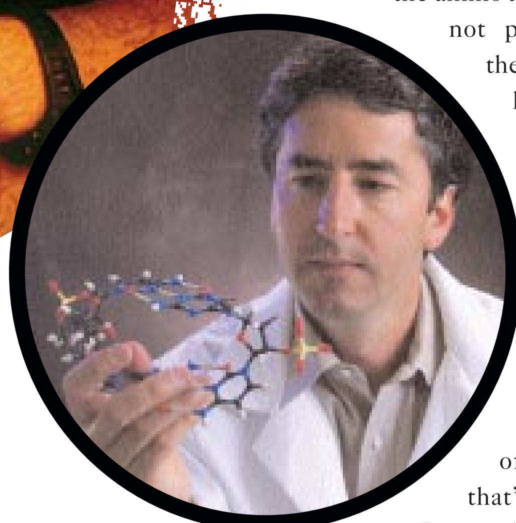
RNA is too complicated, however, to have been synthesized by natural processes and thus was not likely to be the first living entity. This evolutionary gap has led NSCORT researcher Leslie Orgel to study polymerization reactions that could have allowed RNA-like molecules to evolve. Colleague Gerald Joyce is considering even simpler predecessors that would have evolved into RNA. "That's the problem—how to get the Darwinian ball rolling," Joyce said.

But before RNA or even something simpler could form, it had to overcome tremendous odds at the outset. Organic molecules, in parts per trillion of seawater, had to assemble in a hostile atmosphere. Even before the ingredients of life could coagulate, they might have come from somewhere other than within Earth's hostile atmosphere, Bada and others think.

Bada is involved in a branch of exobiology in which researchers study the possibility that comets and interplanetary dust particles gave the primordial soup the needed seasoning for life. Earlier this year, Bada announced finding possible evidence that comets provided Earth with the organic materials and water from which life is thought to have commenced—like seeds thrown from a cosmic hand.

Bada, with Scripps graduate stu-





dent Daniel Glavin and Scripps postdoctoral student Oliver Botta, found amino acids within a meteorite fragment that was apparently part of a comet. As they hope to do with MOD, the researchers looked for a particular amino acid signature within the fragment. The researchers found trace levels of amino acids and concluded that they were not created by biological processes. They deduced that the fragment was a piece of comet after finding only two varieties of amino acids in the sample. Other fragments believed to be from asteroids have contained as many as 70.

Found near the French hamlet of Orgueil in 1864, the meteorite represents not only the first known material on Earth to have come from a comet, but also the possibility of life existing elsewhere in the universe. Although the team determined that the amino acids in the comet were not produced biologically, these amino acids could have been components of life on Earth or other planets.

"Having a meteorite in front of you that's 4.5 billion years old and looking at it to see what it's telling you about the formation of the solar system, that's fascinating to me," Botta said.

The Orgueil meteorite, like many of exobiology's milestones, raises several questions and tentatively answers only a few. Other researchers besides Bada think they can demonstrate that RNA-like components could have been produced in Earth's early oceans, but the extreme dilution of organic materials, whether delivered by comets or naturally occurring on Earth, has yet to be accounted for.

"The goal is to generate through chemical reactions that we can control—ones that are likely to occur in nature and that do not become impure in nature—a system that is alive. We are far away from that," Arrhenius said.

Above, *Stanley L. Miller, exobiology's godfather and first director of the NSCORT exobiology program.* ***Right,*** *Gerald Joyce, an exobiologist at The Scripps Research Institute.*

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NEW AND OLD OCEANS

ON MAY 10, 1962, at a conference in Seattle, Scripps Institution of Oceanography Director Roger Revelle shared a lectern with astronaut John Glenn and Vice President Lyndon B. Johnson.

The occasion was the Second National Conference on the Peaceful Uses of Space. In a speech entitled "Sailing in New and Old Oceans," Revelle gave the oceanographer's perspective on the brand-new era of science exploration. The joint objective of the space scientists and earth scientists "is the highest that science can have," he said.

Although Revelle's speech came at the outset of space exploration in the 1960s, interest in space science was hardly new at Scripps. Since its beginnings, the institution's occupation with earth science and its fascination with space science have blurred the horizon between sea and sky.

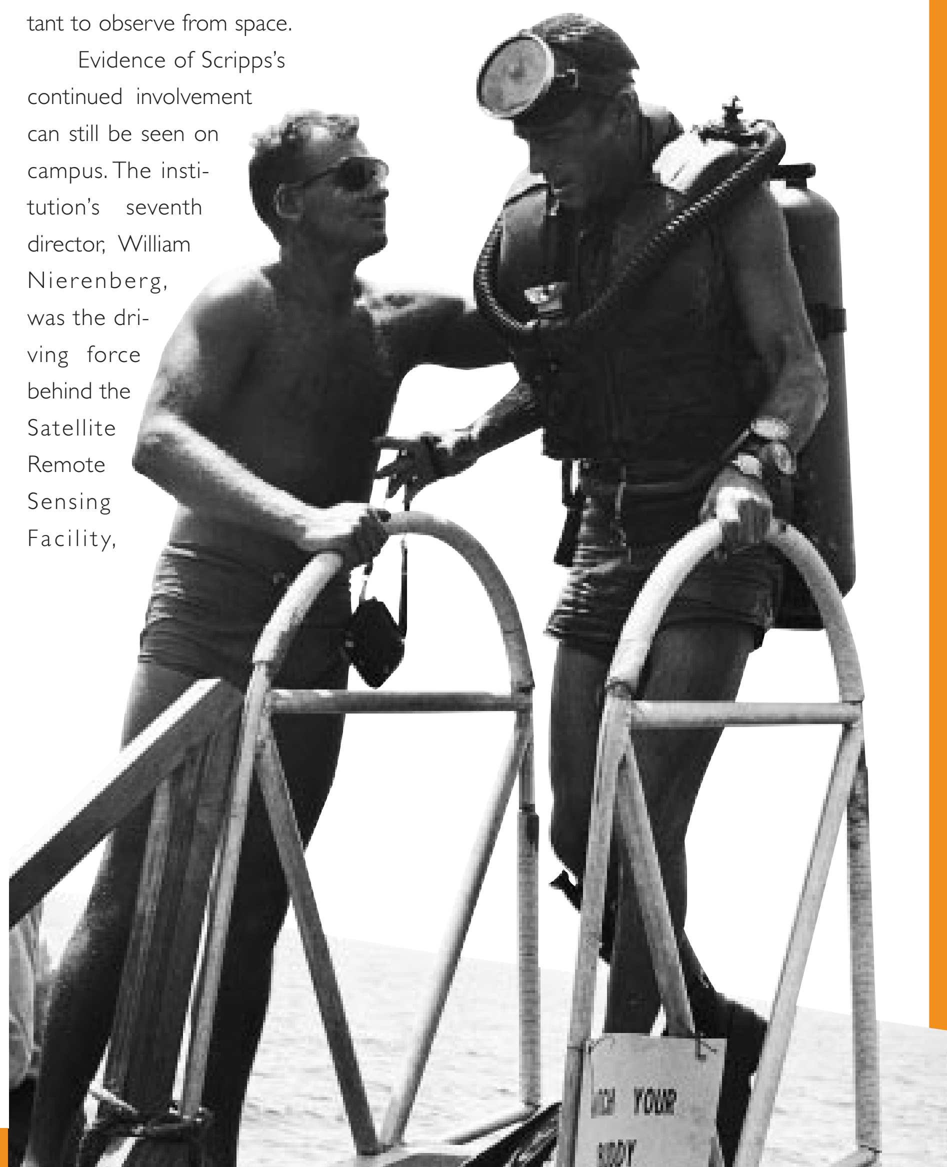
In the 1910s, astronomy was an especially hot pastime and Scripps got in on the action, referring to its instrument-equipped pier as a "marine observatory."

"William Ritter was trying to make the case that biology and astronomy had elements in common that would add to the sum of human knowledge and transform it," explained Scripps historian Eric Mills.

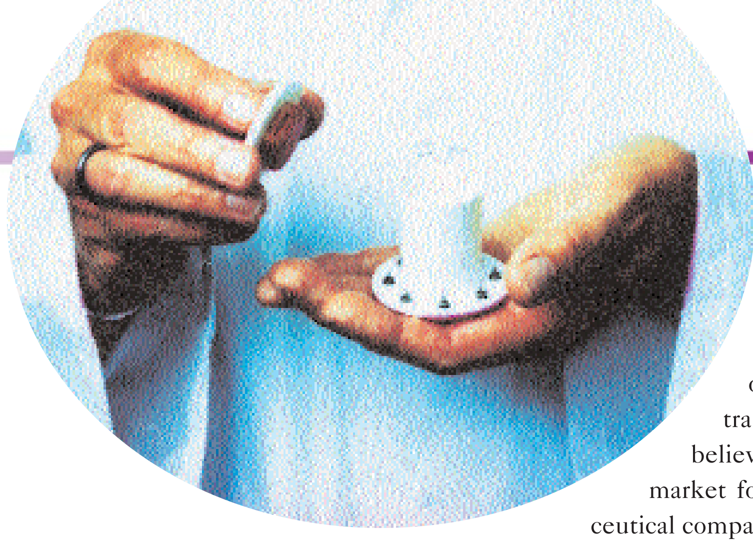
The relationship between biology and astronomy has continued ever since. In 1964, NASA called upon Gifford Ewing, a Scripps doctoral student who returned to the institution in 1978 as a faculty member, to convene a conference on the use of space-based observations of the ocean. From those in attendance, including Scripps scientists Walter Munk and Doug Inman, came advice on the design of observational instruments and on what was most important to observe from space.

Evidence of Scripps's continued involvement can still be seen on campus. The institution's seventh director, William Nierenberg, was the driving force behind the Satellite Remote Sensing Facility, dedicated in 1974. At the facility, researchers can directly study transmissions from Earth-observing satellites and record them on computers.

Scripps researcher Francisco P. J. Valero is involved in one of the most ambitious space launches to date. The *Triana* satellite will have a continuous view of the sunlit side of Earth and give scientists large-scale observations of the planet never before available. It will transmit back data about stratospheric dynamics, solar wind, radiation, and climate, as well as other information that could signal yet another chapter in space discovery.



Top, *Satellite Remote Sensing Facility at Scripps.* **Right,** *Astronaut Scott Carpenter surfacing from a training dive for the Sealab II project at Scripps in 1965.*



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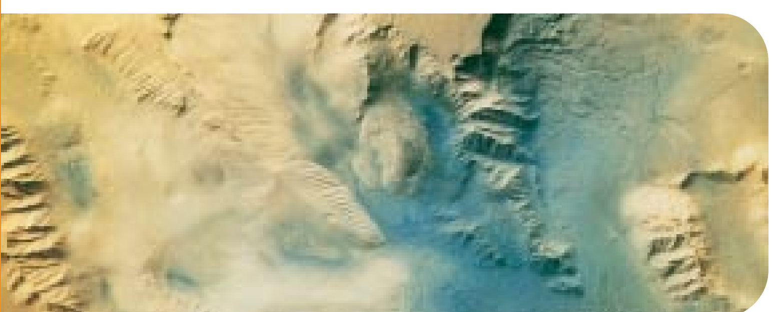
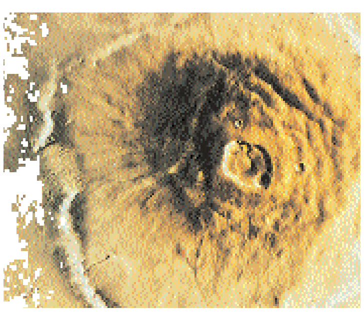
IN THE NOT-SO-DISTANT FUTURE

Most NSCORT research leaders believe one of the greatest successes of the program has been the extensive training students have received. Joyce believes that NSCORT has helped develop a market for exobiologists. For instance, pharmaceutical companies are interested in former NSCORT students conversant in Joyce's specialty, test-tube "evolution." Other students, such as those from Russell Doolittle's lab at UCSD, have found that the comparative DNA sequence analysis they've been carrying out makes them attractive to firms dealing in genomics.

Above, *A full-scale replica of the sublimation oven on MOD.* **Below,** *Features of the Martian surface.*





In addition, former members of Bada's and Miller's groups are now researchers at NASA centers such as the Jet Propulsion Laboratory in Pasadena, California, and the Ames Research Center at Moffett Field in California. To date, 86 students have been graduated from the program.

"Having that training component is what makes NSCORT unique and that's what I'd like to see continue," Joyce said. "The NSCORT program has trained some extraordinary people."

NASA officials haven't yet offered to consider another funding extension; they are waiting for word on what the science priorities of the Bush administration will be.

"Approaching the 10-year anniversary, there will be a discussion whether to continue the NSCORT form of supporting research," said Michael Meyer, NASA Headquarters discipline scientist for astrobiology and exobiology. "Included in the discussion will be whether the recent creation of the NASA Astrobiology Institute could, should, or would take on the NSCORT role of balanced research and training in the interdisciplinary field of exobiology/astrobiology."

Bada has detailed the history of the search for the origins of life in a book—*The Spark of Life: Darwin and the Primeval Soup*, published in 2000—which he co-authored with Christopher Wills at UCSD. He hopes NSCORT survives at least long enough to send MOD off to Mars and to allow enough time to analyze the data the instrument will send back. Then again, it might be enough that the detector project itself survives. MOD was, after all, originally meant to travel on a 2003 mission that was pre-empted, then scrapped altogether.

"The 2007 launch date is the year of my 65th birthday," Bada said. "I can't think of a better way to celebrate than watching the MOD instrument being launched to Mars and then detecting amino acids once it lands on the surface."