by Brittany Moya del Pino

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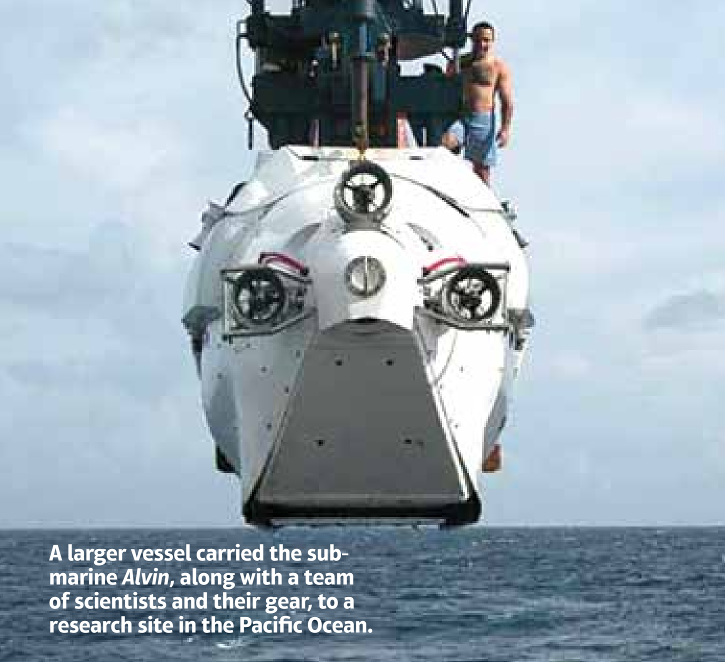
CAN CREATURES LIVING INSIDE OUR PLANET'S CRUST HELP US FIND WHAT MIGHT BE SWIMMING IN SPACE?

Imagine yourself inside a Mini Cooper–sized rocket. Try not to bump into either of the two other crewmembers or any of the computers, buttons, and joysticks that will help steer your course. Little beeps and whizzing sounds come from electronics inside the circular cabin, while the world outside has a thick, eerie silence, and the view from the portholes is black, except for small blobs of light that surround you like millions of greenish stars.

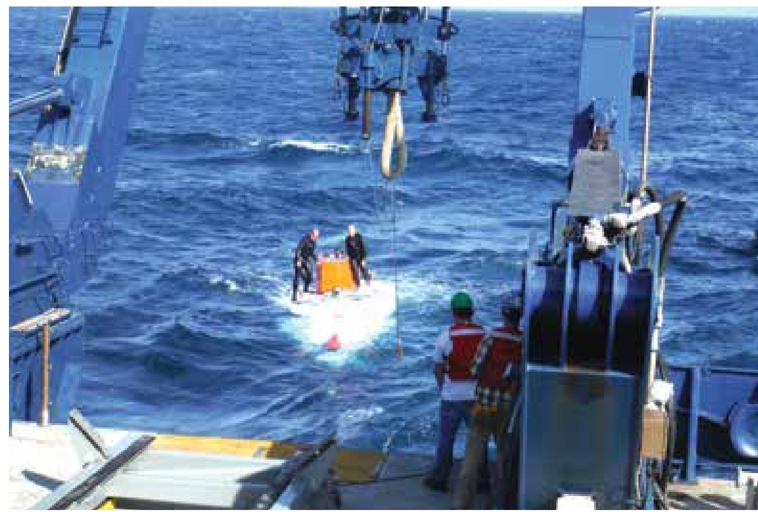
This is what it's like to be on a submarine named *Alvin*, about 200 miles (322 km) off the coast of Washington. Even though *Alvin* is diving toward the center of Earth rather than rocketing away from it, the purpose of this trip has more in common with space exploration than you might think. *Alvin*'s crew is studying how ancient creatures survive, like an alien community, in water-logged rocks beneath the ocean floor.

Journeying toward the Center of the Earth

"You feel like you're in a different world," says Mike Rappé, a marine microbiologist who has been down in *Alvin* three times



A larger vessel carried the submarine *Alvin*, along with a team of scientists and their gear, to a research site in the Pacific Ocean.

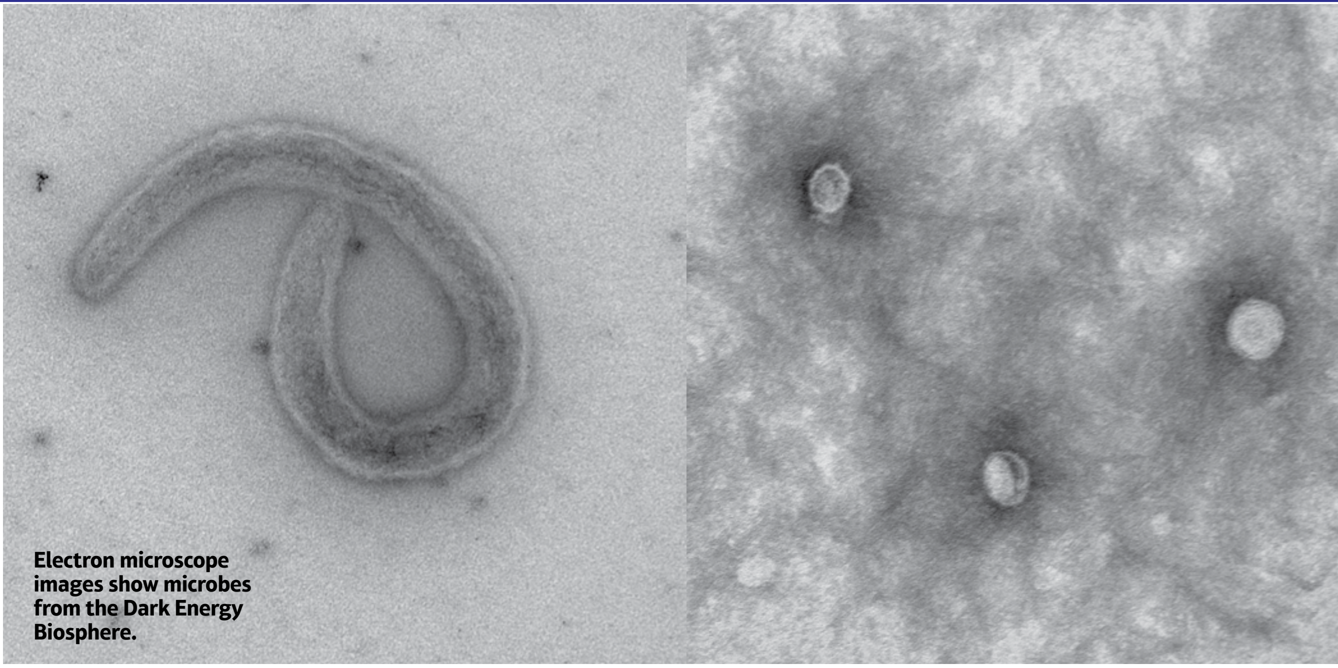


during the last 10 years. He explains that those tiny glowing points visible from *Alvin*'s portholes are actually bioluminescent creatures—and the deep ocean is full of them. "You can see crazy stuff, like a swimming centipede-looking thing or something that looks like a daddy longlegs crawling through the water, creatures that make you wonder, has anyone in science actually described that?" Unfortunately, he doesn't have time to find out.

Alvin takes him around a mile and a half (2.6 km) down to the eastern flank of the Juan de Fuca (pronounced "WAN day FOO-ka") Ridge, an underwater mountain range where fresh crust pushes out from inside the Earth. It's a good place to sample water under the sea floor because of special wells drilled here, capped with lids called CORKs. *Alvin*'s robotic arms operate pumps that pull water from hundreds of meters deep in the wells. They're pumping water long trapped under the planet's surface.

Water at the bottom of the ocean is close to freezing, but the water that comes out of the wells is hot enough to cook an egg. It's also missing ingredients that creatures on our planet normally need to survive: it has no oxygen, almost no organic carbon (stuff like sugar or fat left over from plants or animals that have died), and there's no access to sunlight to use as an energy source. Yet, somehow, this underground labyrinth is swimming with life. Scientists have named it the Dark Energy Biosphere, and they estimate that as much as half of all the microbes on our planet might be living within Earth's crust.

"There are whole new lineages of microbial life down there," Rappé says. "It's like discovering plants for the first time, or fungi. It's like hiking through the jungle and discovering new species of jaguars and other animals everywhere you look." Electron microscope images from his collaborator, Olivia Nigro, show microbes from the Dark Energy Biosphere shaped like rods, spheres, and lemons. One looks like a soup can with long arms sticking out of either end. Analyzing their DNA back in his lab at the Hawaii Institute of Marine Biology, Rappé can tell that these creatures are completely different from what lives outside the crust. About half of the microbes he's found down there are bacteria, but the other half are from an ancient superfamily called *Archaea*, which are known for living in extreme environments where nothing else can survive—places like glacial ice, or oil deposits, or the rainbow-colored sulfur pools of Yellowstone National Park.



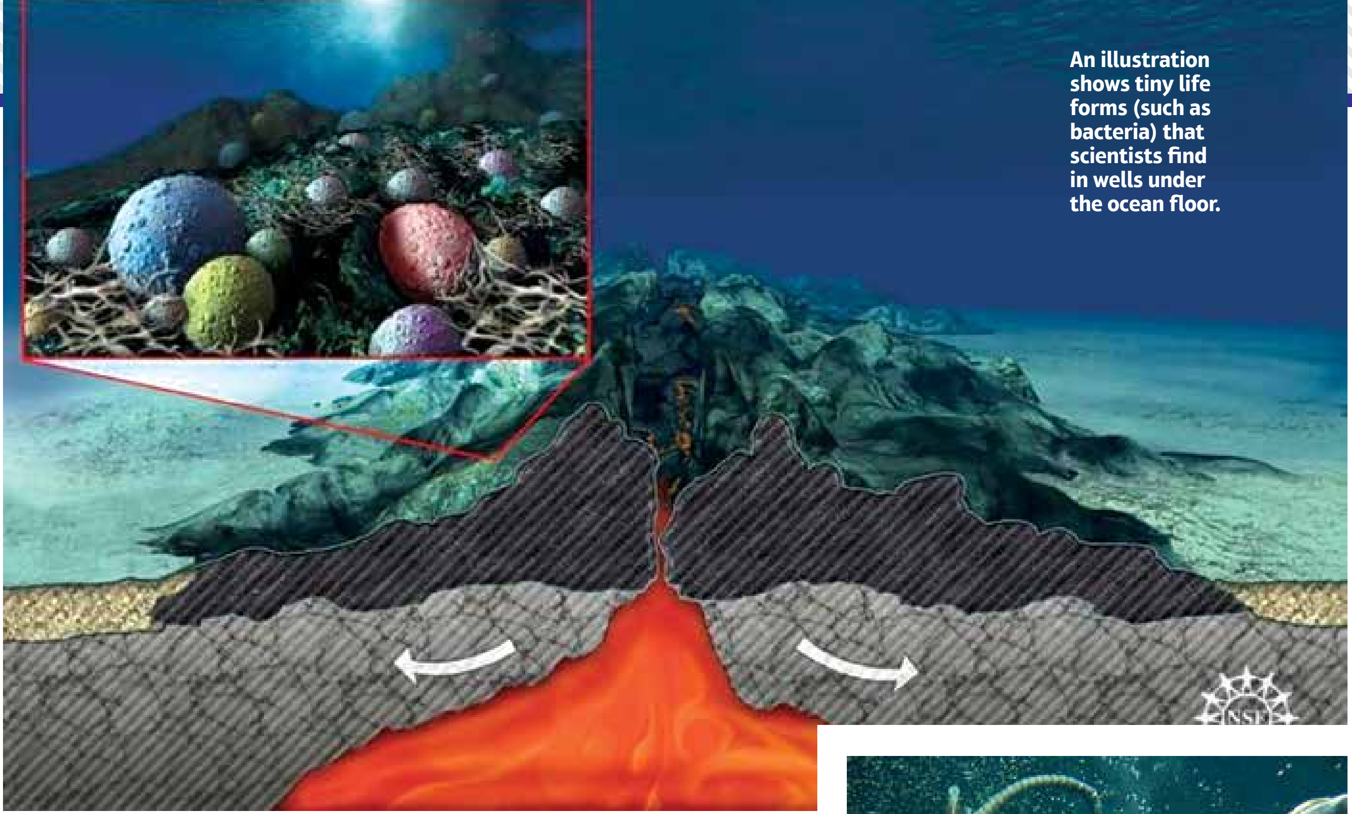
Electron microscope images show microbes from the Dark Energy Biosphere.

It's also clear that creatures from the Dark Energy Biosphere are extremely old. Some scientists think they survive long enough to reproduce only once every 10,000 years. And, because there's literally nothing else to eat down there, they must be getting energy from the surrounding rocks. They may consume hydrogen gas, carbon, or other elements. They could even be sucking electricity directly off of the rocks themselves—which is amazing, of course, but also useful information if you're trying to figure out how the earliest forms of life came to exist on our planet, and how life might be able to survive in other parts of our solar system, or even beyond it.

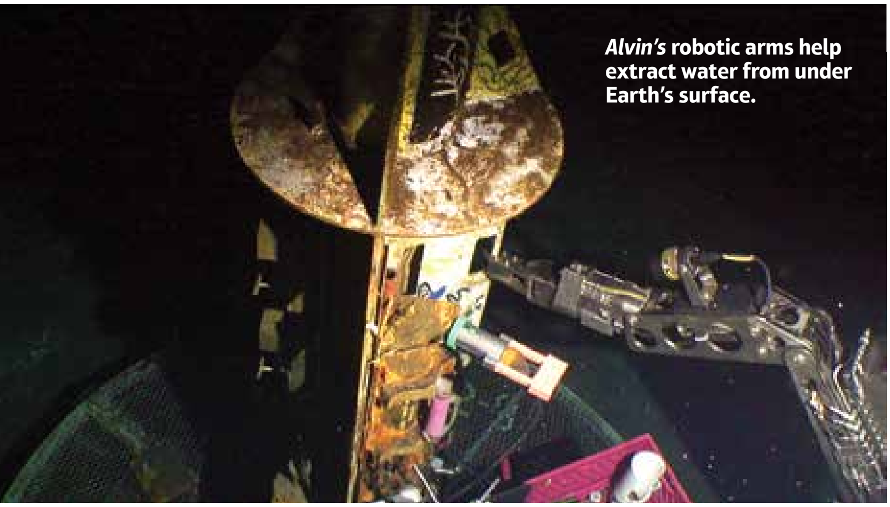
Formed from Mud

After he published his theory of evolution, Charles Darwin came up with a theory about the origin of life on Earth. He described a possible scene in our planet's history in a letter to another scientist as "a warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, etc. . . ." Darwin reasoned that in such a warm little pond, electricity might cause proteins to blob together from smaller chemicals, almost like puzzle pieces sliding together during the vibrations of an earthquake to compose chunks of a bigger picture.

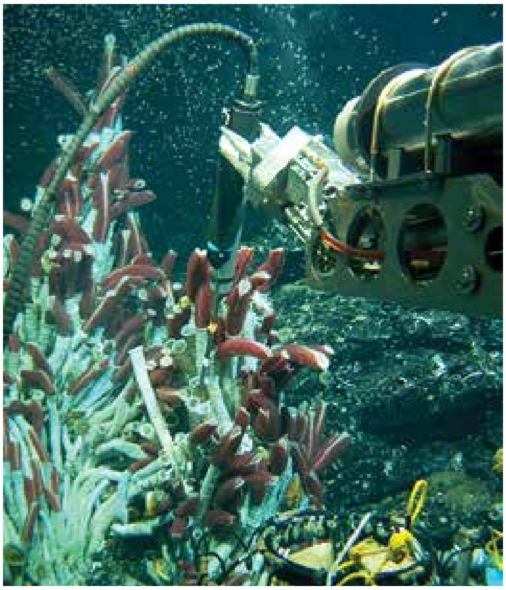
This sounded more than a little crazy back in the 1800s, but scientists eventually showed that Darwin's warm-little-pond idea could actually be true. In the 1950s, two researchers at the University of Chicago, Stanley Miller and Harold Urey, tested the idea. They electrocuted a flask of water with dissolved ammonia, hydrogen, and methane. A couple of days later, the water turned murky brown because of newly formed amino acids, the building blocks of proteins. Decades later, a scientist named David Deamer found fatty



An illustration shows tiny life forms (such as bacteria) that scientists find in wells under the ocean floor.



Alvin's robotic arms help extract water from under Earth's surface.

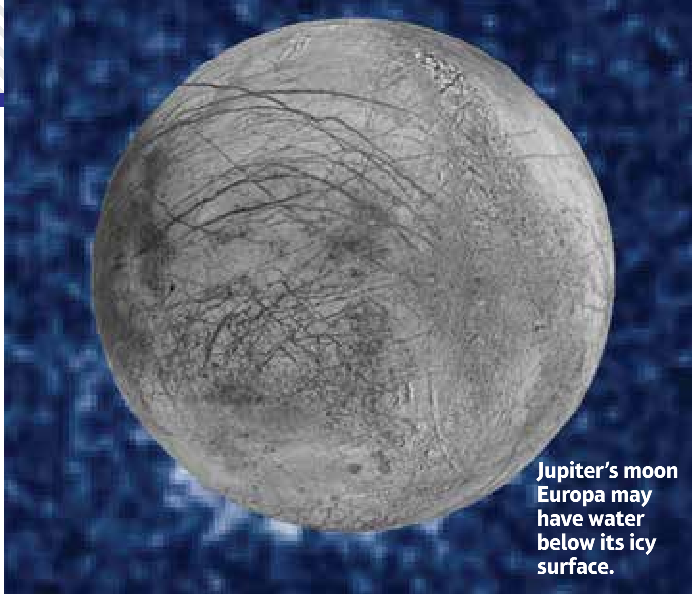


acids inside a meteorite. When he shook up some meteorite dust in water, the fatty acids blobbed together as hollow bubbles, forming something like the membranes that hold cells together.

Today, Laurie Barge, an astrobiologist who works with NASA's Jet Propulsion Laboratory (JPL) in California, has helped take research into the origin of life in a new direction. She wonders if mineral formations that act like batteries helped jolt the first living creatures into existence. Called chimneys, these tube-shaped mineral formations simulate the geological forms found near hydrothermal vents on the ocean floor. These vents host microbes that persist in difficult conditions, just like their cousins found in the Dark Energy Biosphere.

In Laurie Barge's lab, chimneys grow like mineral bamboo.

Scientists believe that life first appeared on our planet about 4.1 billion years ago, so that's the environment Barge tries to simulate in her research. She fills a tank with the type of seawater that existed back then and injects another type of water that would have leaked out of Earth's crust. Cylindrical chimneys grow up like mineral bamboo. Their nooks and crannies contain amino acids that form spontaneously. RNA, a type of genetic molecule, also appears in the mix.



Jupiter's moon Europa may have water below its icy surface.

Then, as electrons flow from the inside of the tube to the outside, the chimneys turn into geological batteries, generating enough current to power a light bulb. The chimneys may also be able to power living cells! Scientists have actually seen bacteria extend their membranes like nanowires, reaching hundreds of times their cell length to suck electrons directly off an electrically charged surface.

Could the first life forms on Earth have started in this way, with a mixture of hot water and minerals spawning simple organic molecules that have the ability to absorb energy and reproduce? Scientists still have a great deal of information to gather before they'll have the answer to those questions. But, in the meantime, they've learned a lot from the Dark Energy Biosphere and lab simulations of hydrothermal vent communities. This research helps us imagine the possibilities for life beyond our planet.

From the Ocean . . . to Outer Space

"Life has always been really intimately linked to its environment," says Barge. "That's why we have to think about geology, too, when we ask about the origin of life. This type of research teaches us a lot about the limits of life. It also leads us to ask, could life on Mars or Europa do that too? It teaches us that we still don't know everything about life on Earth, because we keep finding new things."

Signs of water have been discovered on Mars. Now NASA is planning to send a rover to the Red Planet sometime around 2020 to look for signs of life. NASA is also planning a mission to survey Jupiter's moon Europa. Astronomers have observed plumes that could be water vapor erupting about 125 miles (200 km) out from its surface into a thin atmosphere. And both Europa and Saturn's moon Enceladus appear to have liquid water below their icy crusts.

Though these places do not have oxygen-based atmospheres like Earth's, the Dark Energy Biosphere has proven that, as far as life goes, oxygen isn't actually essential. Liquid water is the key. And, as long as water exists in other parts of the universe, then it's possible we are not alone.

Brittany Moya del Pino lives in Hawaii, where she's always on the lookout for a cool science story to share with *Muse* readers. Her story about white monarch butterflies appeared in the September 2016 issue.

WHAT'S SO SPECIAL ABOUT WATER?

Scientists look for signs of liquid water on other planets because it is the key to life on Earth. Most living creatures on our planet are composed mainly of water, and many of the chemical processes used by Earth's creatures absolutely require it. Ammonia or sulfuric acid could possibly fill the role of water on a planet where temperature and atmospheric pressure are different from Earth's. But water is the most abundant liquid throughout our universe, so the chances are good that if alien life exists, it probably thrives in water.

Water's peculiar chemistry also makes it useful to living things. Composed of one oxygen atom and two hydrogen atoms, each water molecule is slightly negative on the oxygen side and slightly positive on the hydrogen side, just like the poles of a magnet. As a result:

- » Water sticks to itself, which is called **cohesion**, and it sticks to other things, which is called **adhesion**.
- » Water is a great **solvent**, which means it breaks apart other molecules, but it doesn't actually combine with them. This property makes water very good for mixing and transporting chemicals.
- » Water has a **high specific heat capacity**, which means it's very good at absorbing and holding onto lots of energy without getting a lot hotter. This explains why sweating helps us to cool off—water that evaporates from our skin carries extra body heat away with it. It also means that water can help maintain Earth's climate, keeping it from getting too hot or too cold.

—Brittany Moya del Pino