Microbes in the murk

"The biggest ecosystem on this planet—the most populated part of this planet—is the subsurface."

Hans Røy
Aarhus University, Denmark

by Laura Naranjo

Tucked beneath Earth's rich surface layer, tiny organisms eke out a meager living, subsisting in complete darkness with very few food sources. Their existence defies how we often think of life, abounding with oxygen and light. Strangely enough, up to 30 percent of Earth's life forms survive in these extreme places. These microscopic organisms, or microbes, cling to lava vents, linger in permafrost, and lurk in seabeds.

"The biggest ecosystem on this planet—the most populated part of this planet—is the subsurface," said Hans Røy, a researcher at Denmark's Aarhus University who studies aquatic ecology and

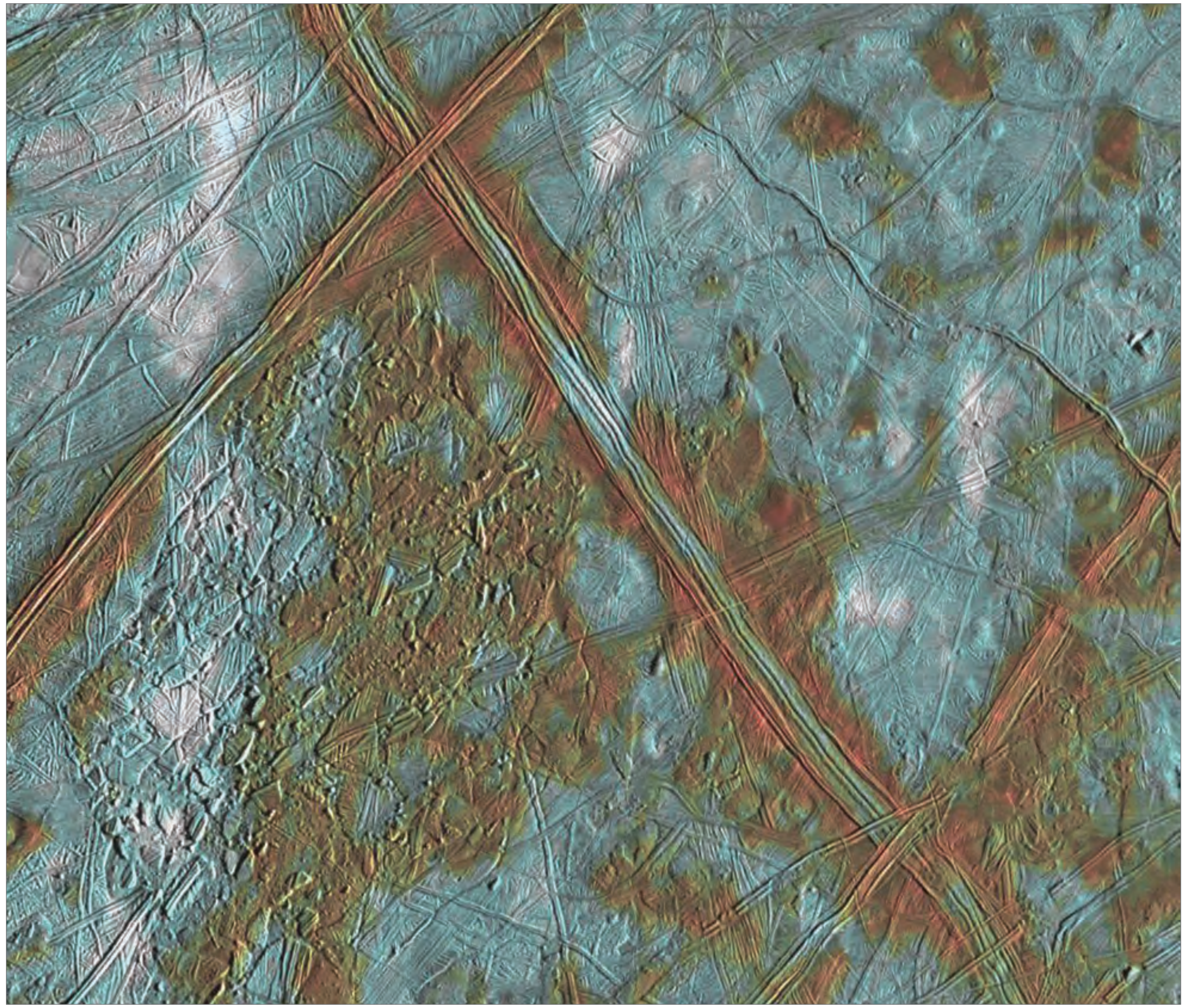
Scientist Hans Røy opens a core sample drilled from the Pacific Ocean seafloor. This sediment can be tens of millions of years old, and contains microbes that provide clues into how organisms survive with no light and little oxygen. (Courtesy B. B. Jørgensen) microbial food webs. Røy seeks out these microbes deep in the seabed, curious about how they survive. "We're interested in what sets the limits for life," he said. How do these organisms survive without food or energy sources? And are they clues to life in other extreme places, such as on other planets?

Searching the gyre

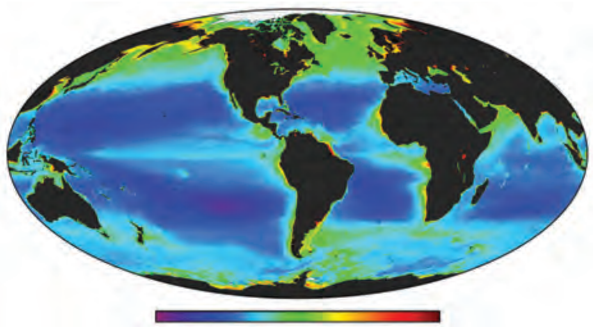
On Earth, scientists find some of the most energy-deprived environments in ocean gyres. Gyres are massive areas of relatively stationary water bound by currents, which sweep nutrients around the gyres rather than into them, rendering them more desolate than the neighboring ocean environments. A group of Røy's colleagues had discovered an oddity in the South Pacific Gyre: its remote and desolate seabed contained oxygen—and microbes—and they suspected the North Pacific Gyre might harbor similar conditions, as well.

Røy and his colleagues spent forty-two days at sea, drilling cores in and around the bed of the North Pacific Gyre. The gyre covers a vast expanse of the ocean, nearly eight million square miles, slightly larger than the size of Russia. It stretches between the coasts of Southeast Asia and North America, and reaches from the equator to 50 degrees north. In fact, the North Pacific Gyre's isolated seabed was once considered a vast marine desert. Scientists have discovered that the gyre harbors life, including the microbes Røy was searching for, along with an unexpected amount of oxygen.

Most life, no matter how small or how deeply buried, requires at least minute amounts of energy. Subsurface microbes acquire this energy by consuming detritus, or the remains of dead organisms, and in that process they deplete oxygen from the seabed. Therefore most of the seabed is anoxic, meaning it contains no oxygen. Oxygen typically exists only in the shallow upper layers of sediment. "In coastal waters, oxygen penetrates maybe 1 to 2 millimeters [0.04 to 0.08 inches] down," Røy said. "In normal ocean sediments, this may be 10 millimeters [0.4 inches]." Yet in the South Pacific Gyre, oxygen penetrated far deeper into the seabed.



This image of Europa, one of Jupiter's moons, shows a region called the Conomara Chaos. The terrain is a jumble of ice rafts that scientists think might be evidence of liquid water below the surface. Studying Earth's energy-poor ecosystems can help scientists understand whether life could exist in similar environments on other planets. (Courtesy NASA Galileo Mission)



This image shows global distribution of chlorophyll in the oceans. Purple indicates the least; red the most. Dark blue areas mark Earth's five major subtropical gyres. Data are from the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS). (Courtesy SeaWiFS Project)

On their way to the North Pacific Gyre, Røy and his team drilled cores in the seabed at several locations as they traveled west along the equator.

Most of the seabed was indeed anoxic below the shallow top layer. However, once the ship veered north into the gyre, the cores told a different story, and they found conditions similar to the South Pacific Gyre. "Suddenly the entire sediment column is oxic, all the way down to the bedrock," Røy said.

In the gyre, one reason oxygen might penetrate so deeply is because algae in the surface waters simply do not produce enough detritus to filter down to the seabed. So along the research trip, he and his colleagues also checked primary productivity for the previous ten years around each core site using data from the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) satellite instrument. Productivity indicates the rate at which algae and phytoplankton in the oceans convert solar energy into biomolecules, in much the same way a cornfield produces corn. Once the researchers entered the North Pacific Gyre, productivity dropped by 50 percent. But it was not nearly low enough to explain the lack of oxygen consumption in the seabed. Why were they finding oxygen in the cores of this extreme environment?

Life in slow motion

Oxygen persisted in the seabed not because of the lower primary productivity present in surface waters, but as a result of how slowly sediment and food were buried. The ocean within the gyre is remote and lacks currents, so the sedimentation rate is only 0.2 millimeters (0.04 inches) per 1,000 years, compared to 10 to 40 centimeters (4 to 16 inches) per 1,000 years along the continental shelves and slopes. "That organic material basically sits right on the surface for thousands of years. And everything that the bacteria can eat, gets eaten before the sediment slowly gets buried," Røy said.

Røy discovered that oxygen existed simply because there were few microbes to consume it. "It's kind of the other way around than you would think. The oxygen in the cores is there because nobody's using it," he said. "It's not really that the seabed microbes were super high adapted to lower energy, there were just a lot fewer of them." Other seabed environments typically contain far more organisms, which consume all the available food and oxygen, leaving most of the seabed anoxic.

In addition to the low population, these microbes live so slowly that they are not consuming even the trace amounts of oxygen and food that remained. They were consuming and respiring, but their metabolism had slowed down so much it could only be measured on a geologic timescale. "If you put a lid on the sediment and tried to suffocate the microbes, it would take 40,000 years," Røy said.

Ancient, dark, and deep

The microbes Røy explored also stretch our assumptions about how long organisms can survive. The North Pacific Gyre cores drilled into sediment dating back 86 million years. Were the microbes also that old? "We have no idea, no way of really investigating that. But they can not be less than 100 years old," Røy said. "But if they are so starved that they use enough energy to just barely keep themselves alive, well then there's really no upper limit to how old they could be."

If the microbes reproduced, even at very slow timescales, some microbes may indeed be distant descendants of ancestors that were alive when dinosaurs roamed the Earth. But it is also possible that some have subsisted in stasis, capable of resuming normal life functions once conditions change. Tori Hoehler, a specialist in space science and astrobiology, studies extreme microbial life forms on Earth to understand what life on other planets might look like. Hoehler said, "These guys down in the deep subsurface are metabolizing anywhere from ten thousand to a million times more slowly."

Other research teams have located ancient microbes in similar deep seabeds and provided them with richer food sources than those typically found in their spare natural habitat. These cells once again metabolized food, and emerged from a sort of suspended animation. This means that the North Pacific Gyre microbes might also revive if more nutrients became available to support them. "It seems that these microbes are sort of sitting there, ready to go," Hoehler said. "And that's at least some indication that they're not in a completely unrevivable state, and maybe they are just going very, very slowly."

Life on Earth and beyond

Studying these microbes gives scientists like Røy and Hoehler a chance to expand the known boundaries for life on Earth, and understand what life forms might thrive in extreme environments that appear uninhabitable. Yet scientists currently know so little about these conditions, even on Earth. Hoehler said, "A third of the life on our planet lives in a physiological state that we have very little insight into."

Exploring extreme environments can also clue scientists into where life on other planets might be found. While countless science fiction books and films have created wildly imaginative scenarios of what aliens might look and act like, it is far more likely that alien life will resemble the tiny humble microbes found deep in Earth's seafloor.

"The kinds of conditions we find deep in the subsurface may be more relevant to thinking about life in these other places," Hoehler said. For instance, it is believed that water exists deep in Europa or in the subsurface of Mars, in conditions similar to Earth's subsurface environment. "A first step in understanding that is knowing how life on Earth copes with limitation of energy," Hoehler said. "And what can that tell us about the prospects for life elsewhere?"

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About the remote sensing data

Satellite	GeoEye SeaStar
Sensor	Sea-Viewing Wide Field-of-View Sensor (SeaWiFS)
Data set	SeaWiFS Level 3
Resolution	9 x 9 kilometer
Parameters	Chlorophyll a and photosynthetically active radiation
Data center	NASA Ocean Biology Processing Group Distributed Active Archive Center (OBPG DAAC)

About the scientists

Tori Hoehler is a scientist with the Space Science and Astrobiology Division at NASA Ames Research Center in California. He studies microbial ecology and biogeochemistry, as well as subsurface and low energy ecosystems and planetary habitability. The NASA Astrobiology Institute and Exobiology Program supported his research. Read more at http://goo.gl/Ndpsqw. (Photograph courtesy B. Thamdrup)

Hans Røy is a researcher at Aarhus University in Denmark. He focuses the ecology of slow growing microorganisms below the surface of our planet, and on how these organisms influence the global element cycles. The Danish National Research Foundation, the German Max Planck Society and the National Science Foundation supported his research. Read more at http://goo.gl/45pLS7. (Photograph courtesy C. Pearce)

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For more information

NASA Ocean Biology Processing Group Distributed Active Archive Center (OBPG DAAC) http://oceancolor.gsfc.nasa.gov

Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) http://oceancolor.gsfc.nasa.gov/SeaWiFS