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The Pacific Ocean's Acidification Laboratory

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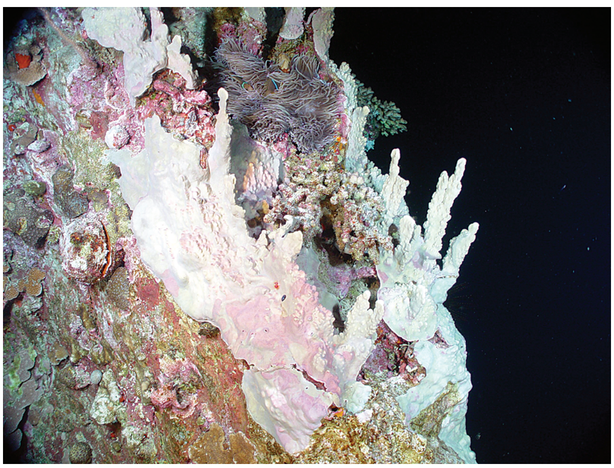
The thermal vents of Maug Island offer a rare chance to study ocean acidification in situ, which gives us a glimpse of what the future might hold.



BOB EMBLEY, NOAA PMEL, PACIFIC RING OF FIRE EXPEDITION

Five years ago, at the quadrennial International Coral Reef Symposium in Okinawa, Japan, a poll of the scientists and resource managers present ranked ocean acidification 38th out of a list of 39 possible threats facing reefs, recalls Rusty Brainard, head of the National Oceanic and Atmospheric Administration's (NOAA's) Coral Reef Ecosystem Division. Last year, at the same conference in Fort Lauderdale, Fla., "Acidification was mentioned almost everywhere."

As it happens, the perfect in vivo laboratory to study ocean acidification lies across the Pacific from Brainard's office in Honolulu, Hawaii: it's the U.S. Commonwealth of the Northern Marianas Islands, located north of Guam and south of Japan. The Marianas offer a unique set of pristine ecosystems living side by side with hydrothermal vents both deep and shallow, spewing gaseous and even liquid CO_2 and SO_2. Near one vent, the pH of the water is 1.

"I've been going to sea for 20 years, and these places are by far the most amazing; they're just mind-boggling," says Bill Chadwick, research professor of volcanology at Oregon State University. Removed as they are from the rest of the world, these waters house an ecosystem that thrives around the first liquid sulfur found on earth and a colony of mussels with paper-thin shells, exquisitely adapted to highly acidic water.

"You can see coral bleaching events all over the world, but you can only look at the effects of acidification at a very few places," says Brainard. "Maug Island is one of the best."

Uninhabited Maug, one of the northernmost Marianas, is a partly submerged crater with an unusually deep lagoon teeming with fish and coral. Hydrothermal vents spewing hot, acidic water create dead zones that span just a few meters and offer a window into how corals react to acid in a natural setting. A little deeper, chemosynthetic communities overlap with photosynthetic ones—one of the few places in the world where the two can be observed together.

Two causes of acidification

As the oceans absorb CO_2 from the atmosphere at the rate of one million tons per hour, the pH of the water is changing. Since the Industrial Revolution, the amount of CO_2 in the atmosphere has risen from 280 to 380 parts per million, and the pH of the ocean water at depths of 1000 meters or less has dropped from roughly 8.2 to 8.1, says Brainard. In the ocean, the rate of change is accelerating: in the past two decades alone, the pH fell from 8.13 to 8.08 at Station ALOHA, which is an abstract point located north of Honolulu. These are the only measurements that exist worldwide for that period. Brainard predicts where such trends might lead if they continue unchecked. "For instance, if we double the 280 figure to 560, we'd expect the tropics to have the same coral cover as the Galapagos, which is very low," he says.

Ocean acidity varies naturally. For example, on many seamounts, cold-water corals grow in undersaturated water—water in which a seashell will naturally dissolve, explains Peter Brewer, an ocean chemist at the Monterey Bay Aquarium Research Institute. "On these seamounts, you don't see dead corals, because they dissolve as soon as they die, and the living ones you see are very old."

With acidification, the proportion of the ocean that's undersaturated will grow, and undoubtedly some species will adapt, says Brewer. "But we don't know which [ones] because the changes have never happened so fast before." The only other known site of shallow CO_2 venting is in Sicily, Italy, where the waters are not pristine and where no case of such adaptation has been found so far.

But that isn't all. A second kind of acidification is going on that's less well-known, says Brewer: milder winters mean oxygen-rich surface waters have not cooled enough to sink as deep as they did in the past, so in effect, the ventilation of the deep oceans is diminishing. As a result, the denizens of the deep receive less oxygen, but they are still producing CO_2 as they breathe. "It's a double whammy," says Brewer. CO_2 levels rise from fossil fuel emissions in the air while reduced ventilation cuts the supply of oxygen and builds up respired CO_2.

A living lab

Lab work helps researchers to understand ocean acidification, but "it's better to observe natural processes that do the manipulation for you," says NOAA oceanographer Richard Feely of the Pacific Marine Environmental Laboratory (PMEL).

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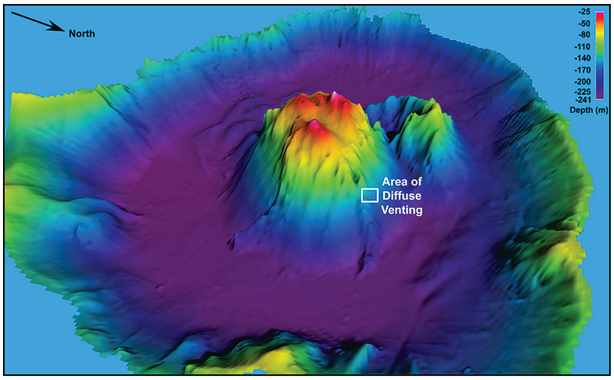

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A 3D view of the Maug Caldera (with 2× vertical exaggeration). The acidic water spewed by hydrothermal vents here creates dead zones—and offers researchers a chance to study in situ how corals react to acid conditions.

In Maug, Brainard has taken samples where the water is 30 feet (ft) deep. "We have water samples from vents coming out at 60 °C, where the water is pH 6.07 and there's no life," he says. "And a few meters away the water is 8.1, and you've got thriving corals." Moving between those two points is like traveling in time, he adds.

In 2004, scientists found that the Maug crater extends to a depth of 820 ft, with a series of vents along the dome at 475 ft that create a localized pH of about 6 just at the limit of the photic zone. It's one of the few places on earth where both photosynthetic and chemosynthetic life coexist. "You've got fish, soft corals, gorgonians, and brittle stars living near the vents, with bacterial mats growing around them," says David Butterfield of PMEL. These bacteria have even been found in the tissues of animals such as worms, mussels, and clams that live near the vents.

Sixty miles away, on the mile-deep summit of the volcano NW Eifuku, CO_2 comes out in the most concentrated form ever measured and with a pH of 1. It originates from two sources: magma and the substrata that are buried when one tectonic plate is pushed under another. As a result, the CO_2 is in liquid form and forms a lake. Nearby, a large bed of mussels thrives in water with a pH of 5.5. Closer examination shows the shells of these mussels are paper-thin, and they have no known predators.

About 500 miles to the south, on a submarine volcano called NW Rota, which is actively erupting at a depth of 1500 ft, "We were impressed to find shrimp near SO_2 vents living in water with a pH of 3–5," recalls Butterfield.

At the Daikoku seamount, marine geologist Robert Embley of NOAA's Vents Program and his colleagues discovered in 2006 the first sulfur volcanism on earth. (Before that, the closest known one was on Jupiter's moon Io.) There, a sulfur lake teemed with crabs and the first fish ever found to live at a hydrothermal vent.

The Nikko seamount, just on the Japanese side of the Exclusive Economic Zone (EEZ) border, boasts one of the world's largest hydrothermal systems in a crater that spans up to one mile across. And unlike other such vents, it's filled with crabs and other creatures. "There must be millions of crabs in there, and fish and worms and mussels everywhere, all related to chemosynthetic life," says Verena Tunnicliffe of the University of Victoria (Canada).

Despite these fascinating examples, Brewer cautions that not all Marianas sites are relevant to the study of ocean acidification. "Many of these vents have a lot of sulfur, which adds more stress and does not simply mimic the rising fossil fuel and respiratory CO_2 signal," he wrote in an e-mail.

Brainard agrees, noting that the rocks (and the water) off Maug have a lot of metals that increase the pH and mitigate the effects of acidification. But still, he says, "This is the only shallow reef we know of where certain spots look just like we expect a lot of reefs will look like in 50 years." Acidification events in the past, he says, "brought mass extinctions, [on] the order of losing half of all genera [at the time]. That's why it's important to study these phenomena now."

Protecting the Marianas Islands

In January 2007, Jay Nelson, head of the Global Ocean Legacy program of the Pew Environment Group, traveled to Saipan, the capital of the U.S. Commonwealth of the Northern Marianas Islands, to investigate the possibility of creating a marine monument in the style of the Papahānaumokuākea Marine National Monument in the Northwestern Hawaiian Islands. The prospective monument would be located around the three northernmost islands: Maug, Asuncion, and Farallon de Pajaros. He had heard they were remote, unfished, and rich in marine life. "At that point we knew nothing about the spectacular underwater geology," Nelson says. "The first expedition dated from 2003, and almost none of the science had been published."

Within a few months, Pew officials were meeting with staff at the White House Council on Environmental Quality, which that fall invited a dozen conservation groups to submit proposals.

The following August, President George W. Bush issued a statement naming seven U.S. sites as being under active consideration for monument status. The Marianas, the biggest component of the proposed monument, would have totaled 115,000 square miles, encompassed the full U.S. EEZ above the latitude 19° north, and included five seamounts, notably Eifuku and Daikoku. Maug, Asuncion, and Farallon were already national parks under local law, but their waters were regulated only by the Western Pacific Regional Fishery Management Council (Wespac) which opposed without success the creation of the Papahānaumokuākea National Monument in 2006.

Although public opinion and the business community in Saipan backed the monument proposal, the elected officials, many of whom have received grants from Wespac, strongly opposed it on grounds that it violated native fishing rights. As a result, the protection for the Marianas Trench Marine National Monument—which was spelled out in Bush's Presidential Proclamation 8335 on January 6, 2009—extends just 50 miles around the three islands and includes only Daikoku and one other seamount.

However, the Minami Kasuga #2 and #3, Fukujin, and NW Eifuku seamounts—along with 15 others further south—were protected from mining and trawling for an area stretching one mile from the center of each vent unit. These restrictions are considered largely unenforceable, though, given the isolation of the seamounts.

"For the seamounts, it's more a recognition than real protection," says Nelson.

"It takes [just] a single trawl run to eradicate sessile animals that can be hundreds of thousands of years old," says Tunnicliffe. "Mile-from-center is the least protection necessary, and it should make a difference; more distance would be better as it gives more buffer for the nonfunctional GPS or inattentive operator."

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