Uncovering the Ocean's Biological Pump

SCIENTISTS REVEAL THE HIDDEN MOVEMENTS OF PARTICLES AND CHEMICALS IN THE SEA

by Elizabeth Halliday

To prevent sample contamination, scientists Phoebe Lam and Dan Ohnemus work inside a plastic bubble lab set up inside a ship. Filters pump clean air into the bubble and keep the space at positive pressure. If the bubble leaks, clean air will leak out and contaminated air won't leak in.

Dan Ohnemus clearly remembers the highlight of his fourth-grade class in Bourne, Mass. He and his classmates made a satellite call to scientists at Woods Hole Oceanographic Institution (WHOI) who were off the Galápagos Islands testing a new generation of remotely operated vehicles (ROVs).

"For a little kid who was interested in science, it was awesome to have a satellite link to a ship somewhere on the other side of the world," Ohnemus said.

He worked hard on his follow-up assignment, a diorama of hydrothermal vents on the seafloor. For the culminating event, the class was invited down the road to WHOI to see scientists actually remotely operating an ROV near the seafloor—in real time, from the auditorium in Redfield Laboratory.

"I sit in that auditorium all the time for lectures," said Ohnemus, before he earned his Ph.D. in 2013 from the MIT-WHOI Joint Program in Oceanography. "But I can remember being in there as a nine-year-old." He and his classmates were packed into the darkened, cavernous room with a live view of the seafloor projected on a towering screen before them. They buzzed with excitement as they watched the ROV *Jason* maneuver around a field of seafloor vents. Ohnemus, laughing, can still recall the stab of jealousy he felt when another kid was picked to try driving *Jason* by remote control.

As it turned out, that day in Redfield wasn't his last chance to peer into a vent field or go to sea himself on a scientific expedition.

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To measure particles at sea, marine geochemist Dan Ohnemus and colleagues literally vacuum them out of seawater samples.

The path to the ocean

Ohnemus is the son of a lobsterman whose working boat is tied up among the dories bobbing in Quissett Harbor in Woods Hole near WHOI. As a kid, Ohnemus would join his dad setting traps in Buzzards Bay.

"I loved going out with him on the boat. I loved to steer. In the summertime I would paint buoys for him."

He even helped his dad monitor water quality at trap sites, as a volunteer for the Buzzards Bay Coalition, doing simple titrations to determine if the water had a healthy amount of oxygen. But fishing as a career seemed fraught with challenges, from the hard labor to frustrating licensing bureaucracy and unexpected diseases that ate away at lobster shells.

A self-described "science kid," Ohnemus cracked open rocks and science books from a young age. At Williams College, he earned double majors in biology and chemistry and then took a break after his rigorous studies to work construction back home in Bourne.

Eventually, science called him back. He answered an ad for a job at WHOI with geochemist Jim Moffett, who was studying elements found in trace quantities, such as iron. These elements are essential for marine life, but they are not evenly distributed in the ocean and are often in limited supply. So understanding where and why trace metals appear in the ocean is a key to explaining where and why life does or doesn't thrive in the ocean.

Boy in the bubble

As a research assistant, Ohnemus learned how to measure vanishingly small amounts of iron and other elements in seawater—and make these measurements on big, rusty metal ships that continually produce metal particles that threaten to ruin their hard-won water samples. To prevent contamination, the researchers build a plastic bubble lab to work inside the ship.

"When I was a kid, my sister and I used to build forts out of clotheslines and towels," he said. "So when I went to sea and had clothesline and plastic and had to essentially build a pressurized 'fort,' it was the most natural thing I've ever done!"

Filters pump clean air into the plastic bubble and keep the space at positive pressure. So if there is a leak in the bubble, clean air will leak out, rather than contaminated air leaking in. Work tables and all metal surfaces are covered in plastic, and hairnets, booties, and gloves are *de rigueur*. Scientists can then work confidently uncontaminated inside the bubble, as the outside surface becomes coated in a film of grime, tiny bits of rusted paint, and flecks of sand from the floor.

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To collect particles at sea, marine geochemist Dan Ohnemus and colleagues wrestle 150-pound, bellybutton-high, battery-operated pumps onto a wire and lower them down to various depths in the ocean.

Particles paint the picture

Ohnemus brought his training in trace-element chemistry with him when decided to pursue a Ph.D. in the Joint Program. But he switched from studying elements dissolved in seawater to the elements that attach to particles that drift and sink in the sea.

The ocean is full of these "particles," which is a catch-all term for everything from sand that blew into the ocean from deserts, to living cells or their skeletal remains, to pellets of poop sinking downward. Particles can be alive, dead, clumped, decomposed, repackaged, or solid rock. If you can catch it on a filter, it's a particle.

Ohnemus and his advisor, former WHOI marine chemist Phoebe Lam, divided the particles they study into two groups, either greater or less than 50 microns, which is roughly half the diameter of a human hair. The particles' tiny size, however, belies the major role they play in the ocean.

"Particles are like the tractor-trailers and trucks of the ocean," Ohnemus explained. "They are moving stuff around, all the time."

Like the tractor-trailers that distribute food from farms to hungry humans, particles in the ocean transport nutrients to depleted areas. They can also transport the equivalent of luxury goods: micronutrients such as iron that are difficult to come by in the ocean but essential for the growth of tiny phytoplankton. Considering that about half of Earth's oxygen is produced by photoplankton at the ocean surface, figuring out what factors regulate where and how well they grow is critical to figuring out how our whole planet operates.

"They are called 'trace' elements because they are found in small, that is, 'trace,' quantities," Lam said. "But their name also could easily be attributed to the fact that many of these elements are useful to 'trace' the movement of water masses and particles in the ocean."

"The stuff inside the 'trucks' is what matters," Ohnemus said, "but sometimes you need to study the trucks themselves, their patterns, to see where they are coming from and how they are getting where they go."

A particular type of evidence

To measure particles at sea, Lam and Ohnemus literally vacuum them out of the water. They wrestle 150-pound, bellybutton-high, battery-operated pumps onto a wire and lower them down to various depths in the ocean. Typically they investigate particles from surface waters down to at least 3,280 feet (1,000 meters) below. Each pump sucks in more than 265 gallons (1,000 liters) of seawater through a filter that captures all the particles.

When the pumps are brought back on deck, the pump head containing the filter is brought to the bubble. Gloves, lab coats, and booties are donned, the filter is withdrawn from the pump with tweezers, the salts are rinsed off, and the filter is set to dry in an oven. The material collected on the filters will range from rusty brown to green, depending where in the world the scientists are sampling. Finally, the filters are bagged and boxed to be analyzed back on land.

"It's definitely strange," Ohnemus said. "We spend days and days collecting these filtered samples, and they can all come back in a backpack."

Back on land, the work really begins. As part of his Ph.D. thesis, Ohnemus developed an analytical procedure to measure 23 different trace elements in particles. The filters, with the particles on them, are completely dissolved with strong acids, and the resulting solution is run through a mass spectrometer to measure the abundance of each element present in the samples.

Priming the pump

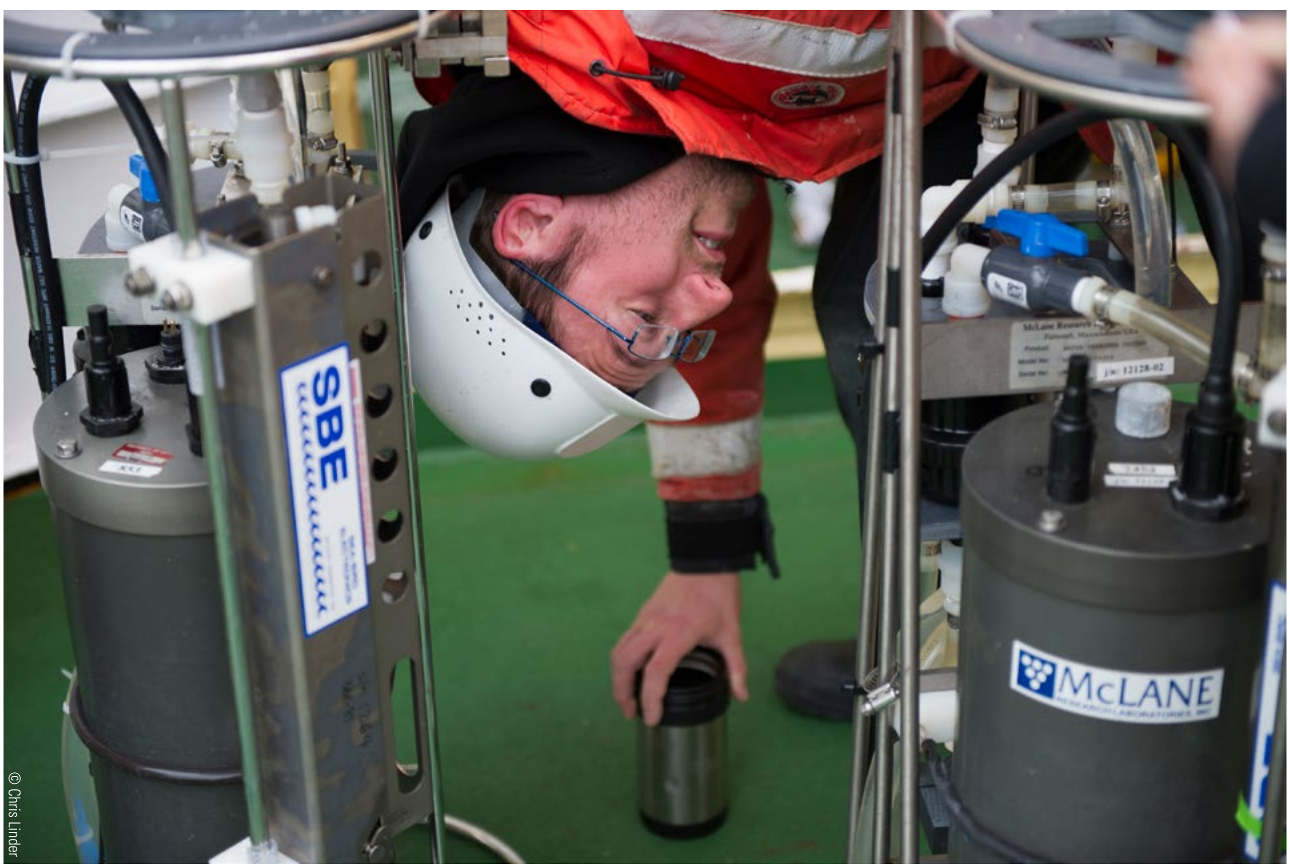
The amount of data they generate is gargantuan: On a single research cruise, there may be dozens of locations where they stop to take 16 particle samples spanning a range of depths in the water below the ship. Ohnemus measured his 23 trace elements from every sample, and Lam examined the organic carbon, calcium carbonate, and opal (a silica mineral) in them.

Together, these trace elements elucidate the movement of particles, which, in turn, take part in a process hidden in the ocean on which our whole planet depends. Scientists call this process the "biological pump," because it is driven by life in the ocean.

It works like this: In sunlit surface waters, plankton take up carbon dioxide absorbed by seawater from the atmosphere. Using photosynthesis, they convert it, just as plants on land do, into organic carbon for their cells. They grow, die, and sink—carrying the organic carbon with them and thus "pumping" carbon from the atmosphere to the deep ocean.

The biological pump plays a key role in regulating Earth's climate, because carbon dioxide is a heat-trapping gas that

Dan Ohnemus unloads pumps that have sucked in seawater samples containing particles floating in the ocean.



Phoebe Lam, WHOI

Scientists find moments of fun and games on long research cruises, including decorating their makeshift bubble lab aboard ship.

is warming up our planet. “The efficiency of the biological pump,” Lam said, “is a battle between how quickly the particles can sink versus how quickly microbes can decompose the organic carbon back to carbon dioxide.”

Typically, big particles made of aggregated cells sink faster, efficiently transporting organic carbon to deeper waters or sediments on the seafloor. Fast-sinking particles are better able to usher carbon to a long-lasting burial at sea.

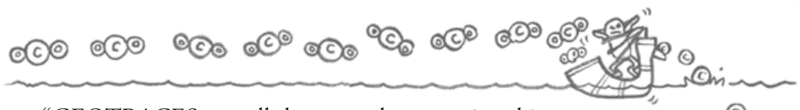
But if particles sink slowly and linger in the upper layers of the ocean, this gives microbes more time to hijack the particle trucks and remove desirable trace elements. The microbes turn the organic carbon back into carbon dioxide, where it easily returns to the atmosphere and contributes to further global warming. “The microbes effectively cause a leak in the pump,” Lam said.

Hither and yon through the oceans

The biological pump functions quite differently in different parts of the oceans, and getting a global view is key to figuring out how the pump and its impact on Earth’s climate may shift in the future.

“Considering how big the ocean is and how important it is to the planet, the most surprising thing for me is how few people are studying it,” Ohnemus said. “The oceans occupy 71 percent of the planet’s surface, and there’s just a really small, collegial, well-functioning group of people out there studying it.”

Global surveys of trace elements in the ocean aren’t something that any one institution or country has the resources to take on. Ohnemus and Lam are part of an international project called GEOTRACES, involving scientists from about 35 nations who are working together on systematic oceanographic cruises to measure and study a wide spectrum of elements, isotopes, and chemicals in oceans around the world. Lisbon, Cape Verde, Bermuda, Durban, Perth, and McMurdo Station in Antarctica are just a few of the ports of call Ohnemus has made crisscrossing oceans on GEOTRACES and other cruises to measure trace metals.



“GEOTRACES gets all these people measuring things together—talking together, taking the same samples from the same place at the same time,” Lam said. “You start putting the puzzle pieces together, to see whether your measurements and theories work with everyone else’s. I didn’t fully appreciate how amazing that would be until we started talking to our colleagues and realizing that it does, in fact, all come together.”

Assembling the puzzle

An example of the puzzle pieces aligning came when a GEOTRACES cruise passed over the Mid-Atlantic Ridge, a chain of volcanic undersea mountains running down the middle of the ocean. Along the ridge, hydrothermal vents spew mineral-rich fluids out of the seafloor like undersea geysers.

As Lam and Ohnemus collected particles, their colleagues analyzed chemicals dissolved in seawater inside and outside the plumes of fluids emanating from the vents. They revealed a picture of the interacting chemical process at play.

The vent plume was the only place in the Atlantic Ocean where particles were rich in iron oxides. They were formed when iron-rich vent fluids hit oxygen-rich seawater. Meanwhile, colleagues measuring dissolved thorium in seawater found a ghostly absence of it within the vent plumes. Together, they deduced that the chemically reactive iron oxides bonded with thorium, mopping it out of the ocean like a sponge.

Every advance like this in understanding the chemistry of our oceans, even those that people consider esoteric, can be valuable, Ohnemus said. “Who knows what knowledge we’re going to need to fix, or even predict, what’s going on with climate change? Even though today, tomorrow, next week, it might not be immediately obvious, the knowledge that we get from studying the ocean is going to be really important over time.

“And it is cool to be even a small part of that,” he said. “You are really lucky to be an oceanographer.”

Now a postdoctoral scientist at Bigelow Laboratory for Ocean Sciences in Boothbay, Maine, Ohnemus hasn’t lost the sense of wonder he had as a fourth-grader. In the middle of a cruise in the Ross Sea off Antarctica in February of 2011, he grabbed a big cup of coffee to prepare for a 5:30 a.m. phone call to the other side of the world. The satellite phone connection was sketchy, but it held up long enough for him to answer questions from students following the scientific adventure from their high school in Roselle Park, New Jersey.

Dan Ohnemu's research was supported by the National Science Foundation's Division of Ocean Sciences and the NSF's Office of Polar Programs, a Williams College Tyng Fellowship, and the J. Seward Johnson Fund and the Stanley W. Watson Student Fellowship Fund at WHOI.

Dan Ohnemus earned his MIT-WHOI Ph.D. in 2013 and is currently conducting postdoctoral research at Bigelow Laboratory for Ocean Sciences, which, despite its marine science prowess and gorgeous facilities, lacks the raw softball talent of WHOI’s Marine Chemistry & Geochemistry Department, not to mention a field. His current research approach involves blasting marine particles with intense synchrotron X-ray light. He maintains a long-term goal of securing an academic job prior to his athletic burnout as a journeyman pitcher.

Dan Ohnemus
Marine Chemistry & Geochemistry

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