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The Iron in Winter
Why North Pacific Phytoplankton Grows in the Dark

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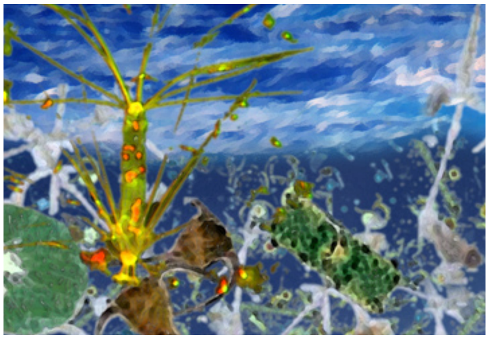


The oceans manage to absorb about half the greenhouse-gas CO_2 produced by humans, but how long this state of affairs will last depends on many unknowns. The role of phytoplankton—tiny marine plants that absorb atmospheric CO_2 and form the first link in most ocean food chains—poses some of the most intriguing mysteries.

One is the paradox of phytoplankton growth in the subpolar regions, which remains roughly constant all year round—despite the fact that plants don't usually grow well in the dark, and in winter the polar regions are very dark indeed.

In 1996 oceanographer Jim Bishop—then a professor at the University of Victoria, now at Berkeley Lab's Earth Sciences Division and an adjunct professor of marine geochemistry at UC Berkeley—came upon a spectacular piece of the polar phytoplankton puzzle.

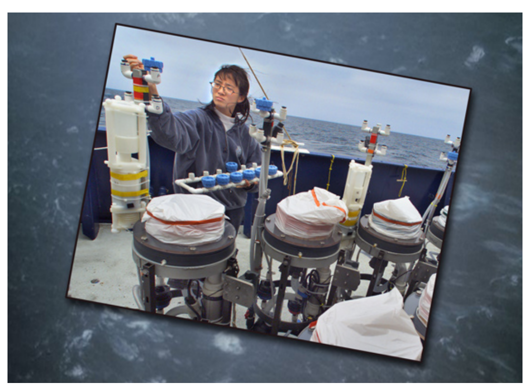
Data from Papa

At Ocean Station Papa in the Gulf of Alaska, oceanographers have established one of the longest time-series of detailed oceanographic data on record. But because of stormy conditions, few samples had been obtained from deep in the ocean during the winter. One way Bishop collects samples is with the Multiple Unit Large Volume Filtration System (MULVFS), an array of collectors lowered over the side by cable that samples the water at regular intervals down to depths of a kilometer.

"I fought tooth and nail to get MULVFS aboard the research vessel that was going to Papa in the winter, betting that we'd have the eight-hour weather window we needed to get the samples," Bishop says. "Fortunately, nature cooperated."

The North Pacific is a region where phytoplankton doesn't grow well at any time of year; while rich in other nutrients, here the plants lack the small increments of iron needed to stimulate growth. Yet Bishop's samples gave evidence of a major plankton bloom.

The bloom Bishop found at Papa in February, 1996 remained unexplained for years. Bishop kept the anomalous samples with him in his collection, and there they stayed until Phoebe Lam, a graduate student at UC Berkeley, arrived at Berkeley Lab to work on her Ph.D. "Jim had an observation he couldn't explain, and he asked me to work on it," says Lam.

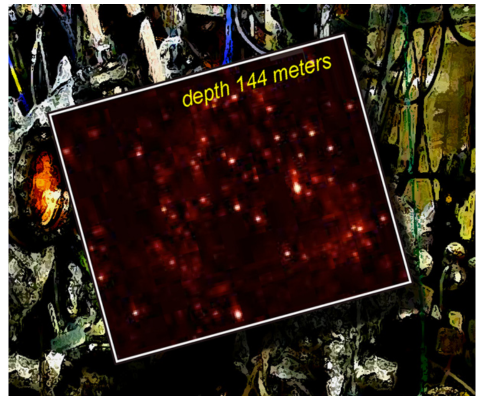


Phoebe Lam with MULVS, the multiple-unit large-volume filtration system.

Working with Glenn Waychunas, who heads the Earth Sciences Division's Molecular Geochemistry and Nano-science Group, and Matthew Marcus at the Advanced Light Source, Lam was able to use the synchrotron to map spatial distributions of minerals, including iron, in the particles in the water samples.

“The ALS made it possible to see the distribution of iron 'hot spots’ embedded within aggregates of biological origin,” says Lam. “Their visual impact was a spur to solving the mystery.”

The hot spots occurred throughout the water column, all the way down to 900 meters deep, but spectroscopy showed that they were rich in iron hydroxides, which are not readily available to phytoplankton. Yet the phytoplankton bloom itself was strong evidence that there'd been a source of available iron in the region. Where was this bioavailable iron coming from?



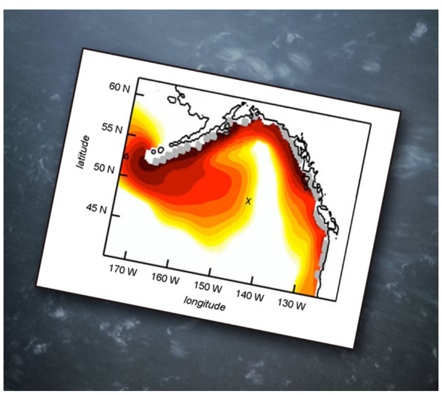
The synchrotron revealed iron compound hot spots associated with biological activity.

“There are three sources of iron in the open ocean,” Lam says, “dust from the atmosphere, iron carried from the continental margins, and upwelling from below. But there was no evidence of dust storms in Asia that could have carried iron to Ocean Station Papa in February, 1996. And if the iron came from upwelling, the concentration of hot spots should have been greater as you looked deeper, which was not the case. That left only the continental margins.”

The nearest continental margins to Ocean Station Papa were the coasts of Western Canada and Alaska, 900 kilometers (560 miles) away. How could bioavailable iron from such a distant source make the long trip? It should have been consumed by plankton long before it reached the open ocean.

Inez Fung is an Earth Sciences Division scientist and a professor in UC Berkeley's Department of Earth and Planetary Sciences, an expert in computer modeling. To test the idea that particulate iron was being transported from the continental margin all the way to Ocean Station Papa, Fung and postdoctoral researcher Cara Henning added a particle tracer to her general-circulation model of the North Pacific.

It showed that particles from the coasts of Canada and Southeast Alaska got nowhere near Ocean Station Papa. “Lo and behold,” Fung says, “we got it from the Aleutians.”



Iron reaches Ocean Station Papa (marked X) from the Aleutian Islands.

A submarine conveyor belt

In the subarctic Pacific the pycnocline—”a region of high density gradient,” Phoebe Lam explains, “which prevents mixing of water above and below it”—averages about 150 meters deep, roughly the depth of the outer continental shelves. In effect, the dense water layer provides a surface on which particles and bioavailable iron can glide out to sea without sinking. Riding the pycnocline, soluble iron can survive the thousand-kilometer trip from the Aleutians to Ocean Station Papa and other regions of the midocean.

In winter the storms hit, roiling the waters and mixing their contents. The deep soluble iron churns to the surface and the phytoplankton blooms. This extra supply of iron in winter, brought near the surface by storms, makes up for the relative lack of light.

In spring and summer, the combination of fewer storms and solar heating make deep mixing impossible, and the deep source of iron is inaccessible. Thus the production of plankton—although never high in this region—remains roughly constant all year round. “We think we have uncovered the mechanism that explains this,” says Lam.

It's ironic, she says, that the iron hot spots she and Waychunas first observed “were probably not involved in growth,” Lam says. “Still, their appearance in the samples was the clue that tipped us off to an unsuspected source of iron in the middle of the subarctic Pacific.”

This is an edited version of an article appearing in the March, 2006 edition of Science@Berkeley Lab, the online science magazine of Lawrence Berkeley National Laboratory. The full-length version, including links to further information, may be accessed at http://www.lbl.gov/Science-Articles/Archive/sabl/2006/Mar/02-winter-iron.html.