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The mystery of the missing deep ocean carbon fixers

In a step toward better understanding how the ocean sequesters carbon, new findings from UC Santa Barbara researchers and collaborators challenge the current view of how carbon dioxide is "fixed" in the sunless ocean depths. UCSB microbial oceanographer Alyson Santoro and colleagues, publishing in the journal Nature Geoscience, present results that help to reconcile discrepancies in accounting for nitrogen supply and dissolved inorganic carbon (DIC) fixation at depth.

"Something that we've been trying to get a better handle on is how much of the carbon in the ocean is getting fixed," Santoro said. "The numbers work out now, which is great."

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Who's doing the fixing?

The ocean is the Earth's largest carbon sink, buffering us from the worst that climate change can throw at us by absorbing a third of our carbon dioxide emissions, which in turn regulates global temperatures. We rely heavily on the ocean for this phenomenon, which is why it's important to fully understand the complex processes that enable it.

“We want to know how carbon moves around the deep ocean, because in order for the ocean to impact the climate, carbon has to make it from the atmosphere to the deep ocean,” Santoro said.

In the ocean, the majority of this inorganic carbon fixing work is conducted by microbes. Phytoplankton, a group of single-celled organisms that take up inorganic carbon dioxide (including dissolved carbon dioxide gas) at the ocean’s surface, are known as autotrophs. They produce their own food in the same way plants on land photosynthesize carbon dioxide and water, producing organic matter (sugars) and oxygen.

The prevailing idea has been that while most DIC fixation happens in the upper, sunlit layer thanks to photosynthetic phytoplankton, a significant amount of non-photosynthetic DIC fixation also occurs in the “dark” layers of the ocean, an assimilation dominated mainly by autotrophic archaea that evolved to oxidize ammonia (a nitrogen-containing compound) for energy rather than sunlight.

However, when tracking these carbon fixing microbes’ nitrogen energy budget through water column sampling, researchers soon found that the numbers weren’t matching up.

“There was a discrepancy between what people would measure when they went out on a ship to measure carbon fixation and what was understood to be the energy sources for microbes,” Santoro said. “We basically couldn’t get the budget to work out for the organisms that are fixing carbon.” They needed energy to do that, she explained, but there didn’t seem to be enough available nitrogen-based energy to go around in the deep ocean for the rates of carbon fixation being reported throughout the water column.

This mystery has long been on the minds of Santoro and the paper’s lead author Barbara Bayer, who have been working to fill this gap in our understanding of the ocean’s carbon cycle for almost a decade. Previous work has explored the hypothesis that maybe these carbon-fixing archaea were more efficient at their jobs than assumed, requiring less nitrogen to fix carbon, though their results indicated that was not the case.

For this paper, the team took a different approach, asking instead how big the contribution of these ammonia oxidizers was to the total dissolved inorganic carbon fixation rates in the dark ocean. To find out, Bayer devised a clever experiment.

“She came up with a way to specifically inhibit their activity in the deep ocean,” Santoro explained. By restricting the oxidizers with a special chemical, she continued, the rate of carbon fixing should be drastically reduced. The inhibitor, phenylacetylene, was confirmed to have no other measurable effects on other community processes.

Their results indicated that despite inhibiting these ammonia oxidizers — mostly archaea that are abundant in the dark ocean — the rate of carbon fixation in the study areas didn’t drop as much as expected.

So if not the ammonia-oxidizing archaea, then who could be doing the carbon fixing in the depths? The list of suspects has grown to include other microbes in the neighborhood, particularly bacteria and some archaea.

“We think that what this means is that the heterotrophs — microorganisms that feed on organic carbon from decomposing microbes and other marine life — are taking up a lot of inorganic carbon in addition to the organic carbon that they usually consume,” Santoro said, “meaning that they’re also responsible for fixing some carbon dioxide.

“And that’s really interesting because even though we know this to be a theoretical possibility, we didn’t really have a quantitative number on what fraction of the carbon in the deep ocean was getting fixed by these heterotrophs versus autotrophs. And now we do.”

These findings also help to paint a clearer picture of how the deep ocean’s food web works.

“There are basic aspects of how the food web works in the deep ocean that we don’t understand,” Santoro said, “and I think of this as figuring out how the very base of the food web in the deep ocean works.”

More mysteries of the deep

Further work in this realm for Santoro and her collaborators will dive into the finer aspects of carbon fixation in the ocean, such as how the nitrogen cycle and carbon cycle interact with other elemental cycles in the ocean, including for iron and copper.

“The other thing we’re trying to figure out is once these organisms fix the carbon into their cells, how does it become available to the rest of the food web?” she noted. “What kinds of organic compounds might they be leaking out of their cells that could be feeding the rest of the food web with?”

Research in this paper was also conducted by Nicola L. Paul, Justine B. Albers and Craig A. Carlson at UCSB; Katharina Kitzinger and Michael Wagner at the University of Vienna as well as Mak A. Saito at Woods Hole Oceanographic Institution.

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