Ocean carbon imaged on the atomic scale

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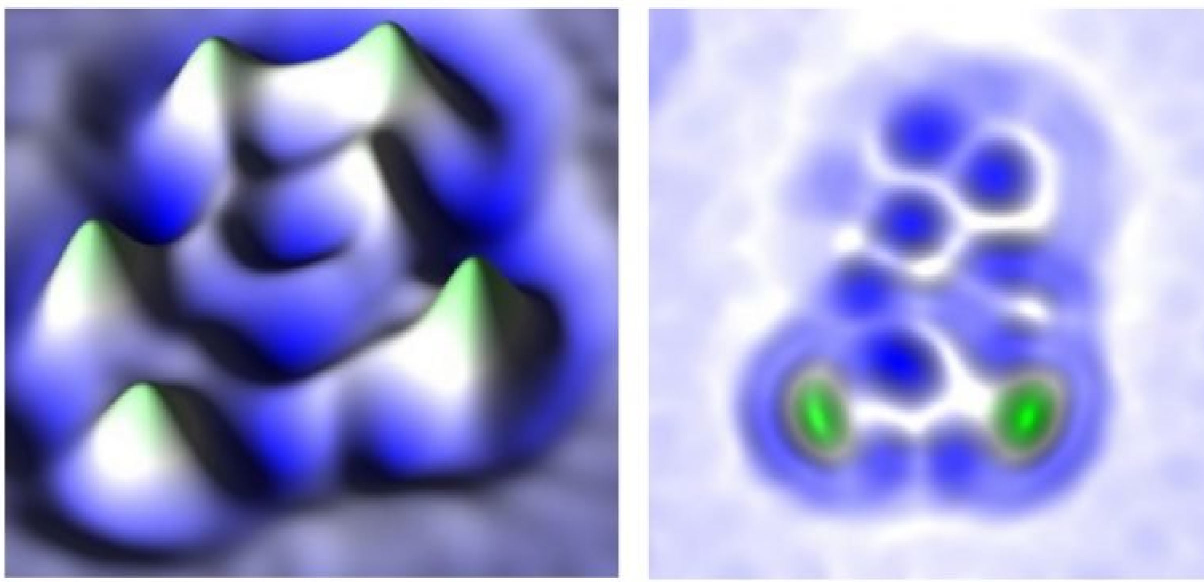

On left: AFM image using a CO-functionalized tip of 5,6,8-trimethyl-2,3-dihydro-1H-cyclopenta(b)naphthalene, a molecule found in the deep ocean. On right: AFM image using a CO-functionalized tip of a molecule found in the deep North Pacific Ocean.

Dissolved Organic Carbon (DOC) in the ocean is one of the largest pools of reduced carbon on Earth. It's about 200 times larger than the living biosphere and comparable in size to the atmospheric CO_2 reservoir. Due to its complexity, less than 10 percent of dissolved organic carbon has been characterized. It's important to understand what this carbon pool is, so we can predict how this pool of carbon will respond to increasing temperatures from climate change.

Scientists from IBM Zurich paired up with chemical oceanographers from the University of Zurich, University of California Irvine and University of California Santa Cruz to image the molecules present in oceanic dissolved organic carbon. This method allows marine scientists to look at the structure of individual molecules in deep ocean basins to gain a better understanding of the ocean carbon cycle. Our research appears today in the peer-reviewed journal *Geophysical Research Letters*.

Mysterious matter

While dissolved organic carbon mainly originates from the surface of the ocean from modern phytoplankton, paradoxically, the mean age (as determined by radiocarbon dating) is about 2,400 years older than we would expect! This indicates that a portion of the carbon survives multiple deep ocean mixing cycles. There are several debated paradigms to explain this enigma. One major theory suggests the long persistence of the deep ocean carbon is explained by its chemical structure. However, the structure of dissolved organic carbon has never been imaged, until now.

Breaking the barriers with synergistic collaborations across disciplines
Emerging tools in analytical chemistry along with chemical oceanography are breaking down the barriers to gain a fuller appreciation of surface and deep dissolved organic carbon. The complexity of compounds in dissolved organic carbon is vast. This oceanic carbon pool contains many thousands of different molecules. At IBM, we use an atomic force microscope (AFM) to image individual molecules with atomic resolution to identify their molecular structure – a method invented by IBM scientists in 2009.

In our research, we resolved samples of dissolved ocean carbon collected from the surface and the deep (2,500 m) waters of the North Pacific to elucidate the reason behind dissolved organic carbon's recalcitrance in the oceans.

Our findings indicate significant differences between the molecules at the surface and those in the deep. By comparison, molecules from deep waters are more planar and feature less aliphatic groups than molecules on the surface. These results support the hypotheses that the old age of deep ocean dissolved organic carbon relates to its structural recalcitrance.

Why should we care about dissolved organic carbon?

Dissolved organic carbon is a huge reservoir of carbon, about equal to the amount of carbon in our atmosphere. In order to understand the carbon cycle and how it will change in oceans with warmer temperatures, we need to understand the recalcitrance behind this ancient pool of marine dissolved organic carbon.

In a world where ocean waters are becoming more and more polluted day by day, and in light of World Environment Day, this method will allow marine scientists to investigate individual chemical structures present in the ocean basins, to better understand the cycling of carbon and uncover the "health" of our oceans.

More information: Direct visualization of individual aromatic compound structures in low molecular weight marine dissolved organic carbon, *Geophysical Research Letters*. DOI: 10.1029/2018GL077457

Provided by IBM