Scientists explore the vast reservoir of dissolved organic matter in oceans

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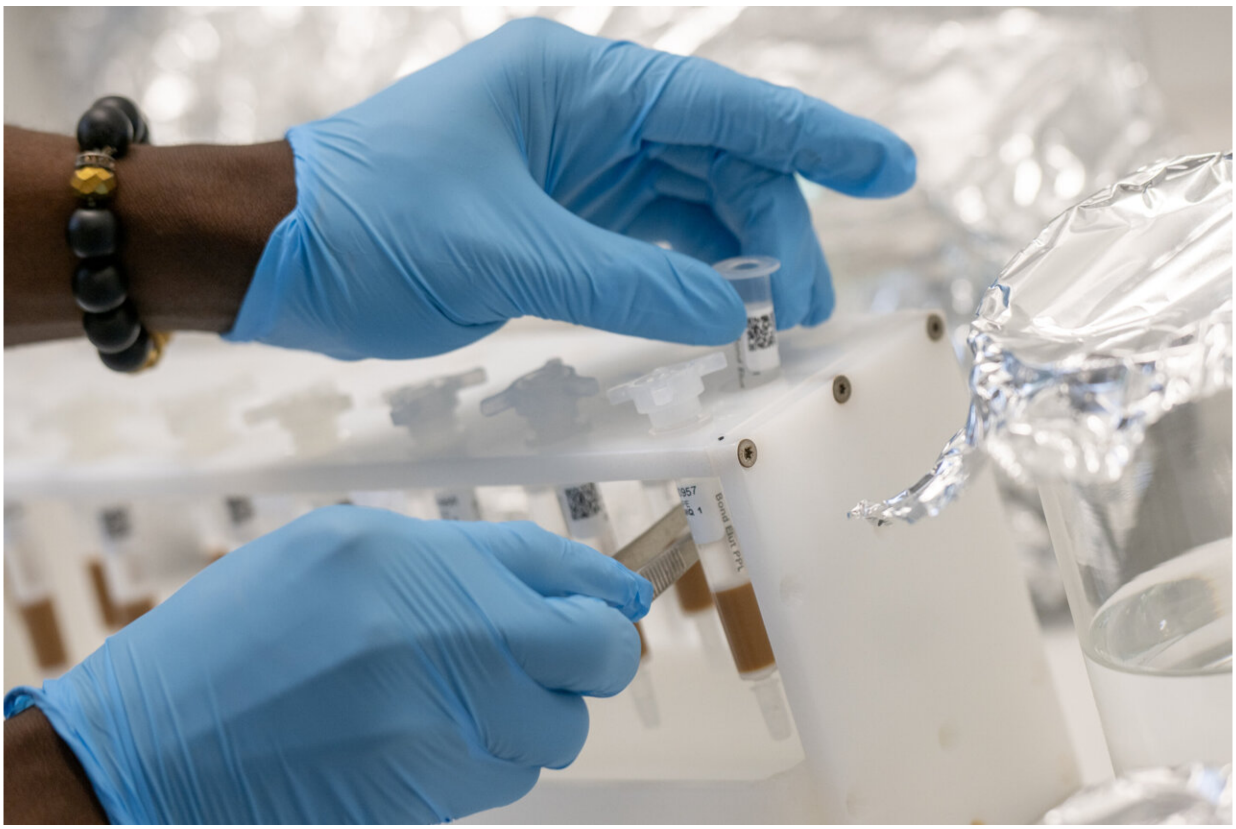

Samples are prepared for further analyses in the lab of the research group Marine Geochemistry - a collaboration between the Max Planck institute for Marine Microbiology, Bremen, and the Institute for Chemistry and Biology of the Marine Environment at the University of oldenburg. The lab, led by Thorsten Dittmar, is home to the world's most powerful ultrahigh-resolution mass spectrometer for marine research. Its analyses of molecular masses are precise enough to enable the assignment of molecular formulae –or put more simply, to determine the number of atoms of elements such as carbon, hydrogen, oxygen and nitrogen that are present in a compound. Credit: Daniel Schmidt / University of Oldenburg

Few things last very long in the world of the open oceans, it would seem. In the light-filled surface layer, microscopic algae convert carbon dioxide and water into biomass via photosynthesis. Individual cells vanish in a matter of hours or days, ingested by other tiny creatures or decomposed by microorganisms such as bacteria. Whereas tree trunks might remain standing for centuries and even millennia on land, the tiny inhabitants of the open seas disappear almost without a trace. Far from shore, for most seafarers, the infinite blue of the ocean is all there is to see.

But in reality, life in the sea also leaves lasting traces. Everywhere in the ocean, from the surface to the deep sea, from the polar regions to the tropics, from the tidal flats to the ocean floor, an invisible mixture of molecules accumulates over time: dissolved organic matter, or DOM for short.

Every liter of seawater contains on average one milligram of these water-soluble carbon compounds. If this figure is extrapolated to the total volume of the oceans, it means that around 700 billion tonnes of carbon are stored in DOM—more than in all living organisms on land and sea combined, and roughly equivalent to the amount of carbon dioxide (CO_2) in the atmosphere.

Part of this gigantic carbon reservoir is incredibly durable. "The oldest molecules are over 10,000 years old," notes Prof. Dr. Thorsten Dittmar. These compounds help prevent part of the organic carbon in the sea from being released straight back into the atmosphere as CO_2. Researchers suspect that this buffer plays an important role in regulating the natural CO_2 content in the atmosphere and therefore in regulating the global climate.

We are surrounded by billions of molecules that we have not yet identified

However, whether or how dissolved organic matter influences our climate on a time scale of centuries to millennia is not precisely known at this stage. "Nor do we know which processes determine the size of this carbon reservoir—or, conversely, how climate change might affect dissolved organic matter," explains Dittmar, head of the Marine Geochemistry bridging group, a collaboration between the Institute for Chemistry and Biology of the Marine Environment (ICBM) and the Max Planck Institute for Marine Microbiology since 2008. For this reason, dissolved organic matter is not factored into current climate models.

Scientists have known of the existence of DOM for more than a century, and they also know that unicellular algae and other microorganisms excrete dissolved organic matter as metabolic products, or when they die. But for a long time, it was unclear what chemical compounds DOM was made of. The analytical methods needed to determine its chemical composition were lacking. "We are surrounded by billions of molecules that we have not yet identified, but which control the habitability of our planet," Dittmar says.

Identifying these molecules is crucial to understanding what happens to them. Only then can researchers generate mathematical models to describe the interactions between the molecules and their environment and thus create the basis for global climate models. Is it due to their structure that some of these compounds survive for millennia? Researchers began finding preliminary answers to this question more than two decades ago.

At Florida State University, where Dittmar was an assistant professor, he and a team of researchers performed the first analyses of seawater samples using a new type of tool, ultrahigh-resolution mass spectrometry, and found thousands of different types of organic molecules. "That was my personal eureka moment," says Dittmar. The results revealed the enormous—and hitherto unimagined—molecular diversity of the dissolved organic matter.

This encouraged Dittmar to delve deeper, even though progress was slow at first. Evaluating the data provided by the mass spectrometer took months back then. In the meantime, the geochemist has made significant headway. His lab in Oldenburg is home to the world's most powerful ultrahigh-resolution mass spectrometer for marine research.

Its analyses of molecular masses are precise enough to enable the assignment of molecular formulae—or put more simply, to determine the number of atoms of elements such as carbon, hydrogen, oxygen and nitrogen that are present in a compound. Thanks to their collaboration with the mathematicians at the ICBM and modern computing power, nowadays the researchers can assess all this data within minutes.

The results show that every liter of seawater contains millions of different substances, although determining the exact quantity is virtually impossible because—as further experiments have indicated—for every molecular formula there are probably many different molecular structures. Another method, nuclear magnetic resonance spectroscopy, has shown how some of the elements in the molecules are linked, thus providing clues about the molecular structure. Dittmar's research group is currently setting up a new laboratory that will house the large instrument required to further this research.

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similar to those in the water column

All these data provide insights into the diverse world of long-lived organic molecules. In this world, microorganisms play a crucial role not only as a source of CO_2, but also in its storage. They ingest organic matter and use their tools, highly specific enzymes, to break down certain molecular bonds and release new substances. Among others, the microbiology research groups in Oldenburg and Bremen also study these organisms and their enzymes. Together, the researchers provide valuable insights into the world of molecules and microbes from different angles.

For example, a comparatively simple experiment conducted by the researchers of the Oldenburg-based Roseobacter Collaborative Research Centre, which recently concluded its activities, illustrates the complexity of the interactions between microorganisms and molecules: the results showed that a single species of bacteria feeding on a single sugar in a lab culture excretes tens of thousands of largely unknown substances.

On the basis of such experiments and observations the researchers have concluded that the long-lived substances are a molecular waste product of enzymatic degradation processes. "The cells actively excrete these substances because they cannot utilize them," explains Dittmar.

According to one hypothesis, some of these substances accumulate because their molecular structure prevents them from being broken down further. However, this hypothesis is called into question by the fact that there are hardly any substances on Earth that microorganisms cannot process.

Consequently, the researchers suspect there is another reason why microorganisms, and especially those in the deep seas, paradoxically do not utilize this abundant food supply. They posit that ingestion, processing and excretion processes produce more and more new compounds in ever lower concentrations. As a result, despite the abundance of molecules, it becomes increasingly difficult for microorganisms to find ones they are able to process.

The work of Prof. Dr. Sinikka Lennartz supports this hypothesis. Lennartz, Junior Professor of Biogeochemical Ocean Modeling at the University of Oldenburg, creates network models that describe the interactions—in very simplified terms here—as follows: an organism in the network ingests a certain substance and excretes two new substances.

Another organism comes along, selects only one of the two substances, and excretes two more into the water, only one of which is processed by a third organism—and so on. This network model delivers results that are "pretty close to the mean concentration and mean age of the dissolved organic matter in the real ocean," says Lennartz.

So the way organisms and molecules interact in their natural environment is decisive, according to the researchers. Dittmar speaks here of the "ecology of molecules," which has a role beyond the open seas: large quantities of long-lived dissolved organic matter are also found on the seabed in certain places. As part of The Cluster of Excellence "The Ocean Floor" based at the University of Bremen, the geochemist's team investigates the interplay between dissolved matter and carbon-containing substances found in particles.

"Presumably, the processes in the ocean floor are similar to those in the water column," says Dittmar. The latter may actually be even more complex, partly because the sedimentary structure serves as an effective physical barrier separating substances from organisms. Together with the microbiologists, the Oldenburg researchers plan to explore in greater detail the processes in the ocean floor and their role in the carbon cycle, and also merge the geological expertise of the Bremen-based researchers with Ol-denburg's ecological and geochemical know-how in a new

Cluster of Excellence.

Dittmar's group is also involved in a number of Oldenburg research projects that focus on shallow marine environments. Here, too, Dittmar sees the need for more research—not least regarding the question of whether carefully calibrated ecosystem management could help these environments to store more carbon than they have done up to now.

Findings on processes that take place on a small scale cannot simply be extrapolated to global scales

However, with all these projects, the following challenge remains: findings on processes that take place on a small scale cannot simply be extrapolated to regional, let alone global scales, such as the world's oceans. The interactions in the microbial network are too complex for that.

But ultimately, this is the only way to find out what role dissolved organic matter plays in the carbon cycle, and thus for our climate. Given these limitations, modeling expert Sinnika Lennartz takes the findings from detailed studies and identifies the most important processes, then integrates only these simplified findings into her larger models.

This approach helps to shed light on the large-scale distribution patterns of dissolved organic matter in the ocean. The researchers know, for example, that dissolved organic matter accumulates in the nutrient-poor regions of subtropical oceans. Presumably, the microorganisms living in these areas are unable to break down these substances because they lack other nutrients such as nitrogen or phosphorus that are crucial for their growth.

"If we factor this into the model, we can reproduce the observed patterns and thus locate large carbon reservoirs in the world's oceans," explains Lennartz.

By combining measurements, experiments and modeling, the researchers thus gradually move closer to their goal of better understanding the molecules and their cycling to be able to integrate this knowledge into global climate models. As the size of the dissolved organic carbon pool is enormous, even small changes could have a major impact on the ocean's ability to store CO_2. Whether this is really the case remains to be seen. For Dittmar, at any rate, the quest to understand the invisible traces of life in the deep blue sea continues.

Provided by University of Oldenburg