TRACING THE SOURCES AND TRANSFORMATIONS OF ORGANIC MATTER IN THE ARCTIC OCEAN

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Research synopsis

Dissolved organic matter (DOM) is the most abundant form of organic matter in all ocean basins, and it serves as the predominant substrate fueling heterotrophic bacterial growth and the "microbial loop" in marine food webs. As such, it is among the largest reactive reservoirs of organic carbon on Earth. It is estimated that 50% or more of the carbon fixed during photosynthesis in the ocean passes through DOM and the "microbial loop". In addition to its central role in marine microbial food webs and the ocean carbon cycle, DOM is responsible for most of the absorption of ultraviolet (UV) light in seawater and is often the most abundant form of nitrogen, phosphorus and trace metals in surface waters. Most, if not all, organisms and biological processes in seawater produce DOM and are thereby potentially important sources of this material. Freshwater drainage from the continents is also an important source of DOM, so this major reservoir of organic matter contains information in its chemical and isotopic composition that integrates biogeochemical processes occurring both on land and in the sea.

The Arctic Ocean is an extremely interesting system in which to study the origins and transformations of DOM, and these studies can provide critical information about the exchanges of materials between continental shelves and ocean basins. Molecular biomarkers and isotopic tracers can be used to distinguish the source as well as diagenetic history of DOM. In some cases, these tracers provide very specific information about the biological origin of DOM (Opsahl and Benner 1997; McCarthy et al. 1998), its mechanism of formation (Wheeler et al. 1996; Benner 1998), and key processes involved in its transformations (Amon et al. 2000; Opsahl and Benner 1998). The Arctic Ocean is unusual in that it has the highest concentrations of DOM of any major ocean basin. A variety of physical, biological and chemical factors influence the cycling of DOM, and in the Arctic Ocean the combination of salinity-driven surface water stratification and high riverine discharge results in elevated concentrations of dissolved organic carbon (DOC) in surface waters. The Arctic Ocean receives a disproportionately large share (10%) of global riverine discharge relative to its volume (1% of global ocean), and in large part the elevated concentrations of DOC appear to result from a major contribution of terrigenous DOM (Guay et al. 1999; Opsahl et al. 1999). A relatively large percentage of DOC (5-33%) in polar surface waters is of terrigenous origin, and lignin-derived phenols have been used to trace the flow pathway and flux of this terrigenous DOM from the Arctic to the North Atlantic (Opsahl et al. 1999). Based on the lignin phenol composition in Siberian rivers and Arctic surface waters, we concluded that most of the terrigenous DOM was derived from gymnosperm vegetation and that photochemical alterations of the DOM in polar surface waters were minimal. These studies clearly demonstrate the usefulness of molecular biomarkers as tracers of the origins, fluxes, transport and transformations of DOM in the Arctic.

Continental shelves occupy a large fraction (~30%) of the Arctic Ocean surface area, and these regions can support substantial rates of primary and secondary production (Aagaard et al. 1999). In general, the magnitude of production and the factors controlling the production, transformations, and fates of plankton-derived organic matter are poorly understood. Molecular biomarkers and isotopic tracers are very useful tracers of plankton-derived organic matter, and they can be applied to studies of the transport and fluxes of shelf-derived DOM to Arctic basins. We recently demonstrated the utility of these biomarkers (neutral sugars and amino acids) in a study of the bacterial utilization of DOM derived from Arctic ice algae (Amon et al. 2000). Terrigenous DOM has low yields of these sugars and amino acids, so plankton-derived DOM can be distinguished from terrigenous DOM based on its chemical signature. The yields of these biomarkers also provide an index of the diagenetic state or bioavailability of the DOM.

Research methods and approaches

The studies described herein require research platforms in the field for the collection and processing of water samples. Our initial efforts in studying the cycling of DOM in the Arctic as part of the SCICEX program relied on bulk measurements of DOC in seawater, and the use of tangential-flow ultrafiltration for the isolation of DOM for detailed chemical and isotopic characterization. The bulk measurements of DOM should be expanded to include DON and DOP. Ultrafiltration of water samples is a relatively slow and tedious procedure that limited the number of samples that could be collected and processed (2 samples per day). We have recently developed HPLC methods for the direct measurement of neutral sugars (Skoog and Benner 1997) and amino sugars (Kaiser and Benner 2000) in small volumes of seawater. A new method for the HPLC determination of D and L enantiomers of amino acids in seawater was also recently introduced (Fitznar et al. 1999). All of these molecular analyses as well as the bulk analyses of DOC, DON, and DOP can be measured in a 100 ml water sample. We have also developed a new solid-phase extraction method for the isolation of dissolved lignin from 10-30 liters of seawater (Louchouarn et al. 2000). The method is relatively quick (8 samples per 6 h) and can easily be carried out aboard ship. These methodological improvements will greatly increase the number of samples that can be collected and processed, and the resulting measurements will be representative of the entire DOM reservoir rather than the ultrafiltered component. It is important to stress that this approach to understanding the sources and transformations of DOM will have much greater significance if it is part of a multidisciplinary effort to understand the transport, fluxes and cycling of organic matter.

National and international partnerships

The Arctic Ocean and its environments are diverse and heterogeneous. It is important that the US SBI research efforts be coordinated with those of other nations that will be working in the Arctic. I have been collaborating on studies of DOM in the Arctic with Dr. Rainer Amon of the Alfred Wegener Institute. This collaboration has been extremely beneficial to both laboratories by promoting the exchange of scientists, methods, and data, as well as by providing samples and research platforms in distinct regions of the Arctic. These collaborations should be promoted by individual scientists and expanded by the organizing committees for these major research efforts.

In addition to coordinated research efforts at the International level, coordination of research efforts at the national level are also needed. The upcoming SBI pan-Arctic meeting should be an important step forward in this effort. However, I believe additional coordination and planning efforts are needed soon after proposals are reviewed and selected for funding. Funded participants should meet to give short presentations of their projects, and a major effort will be required to plan and optimize research cruises.

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