Phytoplankton Dynamics and Carbon Cycling in the Equatorial Pacific Ocean: Control by Si and Fe

Project summary

Of the many linkages that connect the cycles of chemical elements in the ocean-atmosphere-biosphere system, the control of the oceanic carbon cycle by the cycles of several required nutrients is one of the most important. Phytoplankton photosynthesis, export of particulate organic carbon (POC) to the deep ocean and the subsequent respiratory breakdown of that POC to CO_2 comprise a 'biological pump' which extracts CO_2 from the atmosphere and moves it into the deep ocean. There is now evidence from ice-core records that changes in the global-scale efficiency of that pump have played a major role in controlling atmospheric CO_2 concentrations on glacial/interglacial time scales.

The main limiting nutrients for phytoplankton in the upper ocean are nitrogen (N), phosphorus (P), silicon (Si) and iron (Fe). Each limits phytoplankton growth in certain ocean habitats, although Si can limit only one functional group of phytoplankton, the diatoms. In certain high-nutrient, low-chlorophyll (HNLC) areas high concentrations of nitrate and phosphate persist year-round, increasing the potential importance of both Si limitation and Fe limitation. HNLC areas are also of crucial importance in determining the global-scale efficiency of the biological pump. In areas where much of the N and P delivered to surface waters goes unused, relatively little of the dissolved inorganic carbon (DIC) delivered to the upper ocean with those nutrients is taken up by phytoplankton and the capacity of the ocean to extract CO_2 from the atmosphere is diminished. Two HNLC systems are of particular interest in this regard, the Southern Ocean and the equatorial Pacific. In the Southern Ocean, glacial/interglacial changes in Fe availability may have produced large changes in POC export, driving the well-documented changes in atmospheric CO_2. In the equatorial Pacific, the combination of active upwelling at the equator and relatively inefficient use of the upwelled N, P and DIC by phytoplankton make it the largest oceanic source of CO_2 to the atmosphere under present conditions. This proposal seeks support for a combined program of research and education, focused on the roles of Si and Fe in regulating phytoplankton productivity, the competitive success of three important functional groups within the phytoplankton (diatoms, coccolithophores and picoplankton) and ocean/atmosphere CO_2 exchange in HNLC systems. While the educational effort will consider both the Southern Ocean and the equatorial Pacific, the research phase will be conducted in the upwelling zone of the eastern equatorial Pacific (EEP).

Field studies and modeling efforts have provided evidence of both Fe limitation and Si limitation in the EEP. In addition, Fe-enrichment experiments have shown that diatoms are usually stimulated more than other phytoplankton by release from Fe limitation. Si availability and Fe availability can also interact to control POC production and export because low [Fe] increases the Si:C and Si:N ratios of diatoms. We will investigate these relationships through experiments using ^{14}C, ^{32}Si, and ^{15}N tracers to measure rates of photosynthesis, calcification (by coccolithophores), Si uptake (by diatoms) and N uptake in the EEP. ^{14}C and ^{15}N uptake experiments will be size-fractionated to distinguish between uptake by picoplankton (cells < 3 μm) and the larger fraction, which includes both diatoms and coccolithophores. These experiments will be combined with measurements of nutrient concentrations, dissolved and particulate Fe concentrations and standing stocks of chlorophyll-*a*, POC, particulate organic nitrogen (PON), $CaCO_3$ and biogenic SiO_2. Chlorophyll-*a* POC and PON will be size-fractionated to distinguish between picoplankton and larger cells. We will also determine the abundances of diatoms, coccolithophores and picoplankton by flow cytometry, by automated (Flow CAM) microscopy and by regular microscopy. We will obtain these data throughout the upper 120-150 m between 5° N and 5° S, and conduct multi-day growth experiments in which six different combinations of Si, Fe and germanium (a specific inhibitor of diatom growth) are added. Taken together, the field experiments and improved physical-biogeochemical model simulations will evaluate the importance of Si limitation, Fe limitation and any interactions between Fe and Si in controlling the competitive success of diatoms, coccolithophores and picoplankton and drawdown of CO_2 in the EEP.

The educational phase of the project seeks to help high school and elementary school teachers present state-of-the-art information on oceanic biogeochemistry, the global C cycle and climate to their classes, and use ongoing research as a teaching tool. We will do this through short courses for teachers, preparation (with the help and advice of those teachers) of instructional materials for high school and elementary school students and inclusion of a teacher on each cruise to experience seagoing biogeochemical research first-hand, and help interpret the material for other teachers and students.