GOALS

The long-term goals of this work are to test the hypothesis that metals, especially iron, regulate rates of primary production in High Nitrate, Low Chlorophyll (HNLC) areas of the ocean. An important corollary of this hypothesis is that it might be feasible to regulate productivity in small patches in the open ocean by addition of small amounts of iron. The ability to produce "mini-blooms" would be an extremely valuable experimental tool for the study of ocean biogeochemistry.

OBJECTIVES

The primary objective of the work undertaken in 1993 was to perform the first mesoscale (64 km²) iron enrichment experiment in the open ocean. We also conducted a study of trace metal distributions downstream of the Galapagos Islands. The area downstream of the Islands has elevated chlorophyll concentrations. We hypothesized this to be a natural analog of an open ocean iron enrichment experiment in which the iron was derived from the Islands.

APPROACH

The implementation of a mesoscale iron enrichment experiment, originally conceived by John Martin, required that considerable physical, chemical, and logistical obstacles be overcome. A series of experiments were performed to assess the feasibility of performing an open ocean iron fertilization experiment. These experiments indicated that it was feasible to perform an open ocean iron addition experiment. The first fertilization experiment was then conducted in October/November 1993 with a team of scientists from across the US and England. The fertilization experiment was immediately followed by the study of the Galapagos Plume.

TASKS COMPLETED

In previous studies, enrichment experiments were performed to determine which form would be most biologically available, cost effective and simulate the chemical form of atmospherically derived iron. Under this project, physical and chemical models were used to predict the speciation, solubility, and the final concentration of iron in surface waters injected with acidic iron sulfate. These models were developed in collaboration with Dr. Stephane Blain (University of Brest, France) during his three month visit to Moss Landing Marine Laboratories. Collaborative discussions with Drs. Tim Stanton and Andrew Watson (Navy Post Graduate School, Monterey, CA and Plymouth Marine Lab, UK respectively) resulted in a deployment strategy utilizing a lagrangian reference buoy about which the experiment would be carried out, and the results monitored. A system was designed to deliver regulated amounts of iron into the
September 27, 1994

Scientific Officer Code: 323C
Dr. Edward J. Green
Office of Naval Research
Ballston Tower One
800 N. Quincy Street
Arlington, VA 22217-5000

RE: Grant No. N00014-94-1-0125 - "Method Development for an
Unenclosed Mesoscale Iron Enrichment"

Dear Dr. Green,

Enclosed is the original and two (2) copies of Moss Landing Marine
Laboratories' annual progress report for the period October 1, 1993 to

If you have any questions, please call me at (408) 924-1435.

Thank you.

Bill Yabumoto
Contracts & Grants Analyst

Account No. 21-1509-0494

cc: ACO - N63375 (1)
    Director, Naval Research Lab - Code 2627 (1)
    Defense Technical Information Center (2)
ships wake along with an inert tracer (sulfur hexafluoride). Utilizing the R/V Sproul, a trial injection off the California Coast in which 800 liters of a 0.5 M FeSO₄ was introduced into the ship's wake over a 1.5 km² area, was used to test these predictions. Iron concentrations in this small scale patch were determined continually during the experiment using a shipboard colorimetric method, as the ship steamed in transects through the enriched patch. These preliminary results indicated excellent spatial agreement with model predictions and final concentrations which were consistent with the chemical model.

This equipment and strategy was then used to perform an open ocean fertilization experiment in HNLC waters south of the Galapagos Islands. The mixed layer (30 m) iron concentration in a 64 km² patch was raised from ca. <0.1 nM to a mean value of 3.5 nM by adding 500 kg iron to the mixed layer. This was sufficient iron to cause complete depletion of the available major nutrients (nitrate, phosphate and silicate). Chemical and biological properties of the patch were tracked for 9 days. A survey of metal distributions in the waters upstream and downstream of the Galapagos Islands was then conducted. Shipboard measurements of nutrients, oxygen and chlorophyll were performed on both cruises. Trace metal samples, particulate organic carbon samples, dissolved organic carbon samples and plankton species samples were collected on both legs of the cruise and are now being processed in the laboratory.

To date we have competed analyses of all particulate trace metal samples representing two size fractions (.4μm < x < 5μm and >5μm) for Fe, Cd, Co, Cu, Ni, Pb, Zn and Al. All dissolved metals for the IronEx leg have been analyzed and dissolved analyses of samples from the PlumEx leg are continuing. Analyses of samples for POC, DOC and species composition are underway.

ACCOMPLISHMENTS

The first iron enrichment experiment was a major success. Addition of iron to a 64 km² patch produced increases in chlorophyll concentration and primary production rates that were 3 fold elevated over background values. We were able to track this patch for 9 days before returning to port. These results demonstrate that iron does regulate biological rates in HNLC areas of the ocean. They also clearly indicate the feasibility of performing controlled experiments on open ocean ecosystems for significant periods of time. It is clear, however, that the ecosystem in the fertilized patch did not behave similarly to that observed in containers on board ship. This difference has been attributed to the short residence time of iron in the patch, whereas in bottles, there is no removal of iron from the system.

We are continuing analysis of samples, planning the next IronEx experiment (May-June of '95) and working up the results of our last field effort. Due to the interest in the experiment and the untimely death of John Martin, Kenneth Coale has been asked to act as guest editor of a special issue of Deep-Sea Research honoring John Martin and focusing on the results of the IronEx and PlumEx cruises. Proposed submissions for this issue are appended at the end of this report.

Papers Published

Martin, J. H. and S. E. Fitzwater. 1992. Dissolved organic carbon in the Atlantic,


Papers in Press or Submitted


Invited conference presentations


Johnson, K. S. Invited speaker, USC SeaGrant Program Review, March 17, 1992, Los Angeles, CA. "Metal fluxes from sediments at the Whites Point Sewage Outfall".


Barber, R., S. Lindley, R. Bidigare, M. Latasa, M. Ondrusek, K. Buck, F. Chavez, S.


Contributed conference presentations


number of undergraduate students 0
number of graduate students 1
number of post-docs 0
other tech personnel 3
number of female graduate students 0
number of minority graduate students 0
number of asian graduate students 0

Deep-Sea Research, John Martin Special Issue, Proposed Submissions


Gordon, M., Coale, K. H. and Johnson, K. S. Trace metal distributions and partitioning during the IronEx and PlumEx experiments in the Equatorial Pacific.


Friederich, G. E., Sakamoto, C. M. and Millero, F. Surface seawater distributions of inorganic carbon and nutrients within the Galapagos Plume: Results from the PlumEx experiments using automated chemical mapping.

Stanton, T., et al., Watson, A. et al. The open ocean iron enrichment experiment: Physical evolution of the iron enriched patch.


Lindly S. et al., Changes in the quantum yield of photosynthesis in phytoplankton during the IronEx and PlumEx experiments.

Chisholm et al. The Picoplankton response to iron addition (Plume and Patch and Bottles).

Chisholm et al. The changes in phytoplankton community size structure (flow cytometrically derived and size-fractioned chlorophyll) in iron addition (Plume and Patch and Bottles).


Ondrusek, M., Latasa, M. M., Bidigare, R. Pigment composition and community structure in the IronEx and PlumEx experiments.

Tindale, N. and Seymour, J., and ? Composition, concentration and chemical fluxes
of atmospheric aerosols during PlumEx. Results of single particle analysis.

Collins, C., Steger, J. and G. Montenegro. Upper ocean circulation during the Galapagos Plume experiment: Implications for source waters and mixing.


Lewis, M. R. et al., Bio-optical characteristics of the IronEx experiment and beyond: Results from the optical buoys that would not die. (or: The optical energizer bunny explores the Pacific).