# SOFeX Cruise History and Purpose

## SOFeX Cruise, January-February, 2002

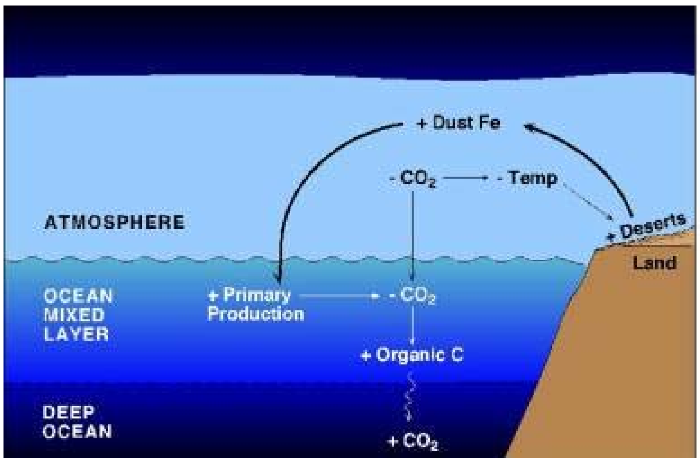


**Cruise Dates**: January 5 - February 26, 2002
**Cruise Location**: Southern Ocean
**Ships**: **RV Revelle**, **RV Melville**, **USCG Polar Star**

**List of institutions involved and the principal investigators.**

### Cruise History and Background

We're sailing on the Southern Ocean Iron Experiment (SOFeX) expedition with the goal of testing a major hypothesis about climate. One of the great mysteries of the earth's climate is the process that controls the onset of glacial periods (an ice age). Changes in the orbit of the earth (the Milankovitch Cycles) seem to control the timing of glacial cycles, but the small orbital variations don't affect the earth's temperature enough to create an ice age. Something else must amplify these changes.




We're going to the Southern Ocean to test **John Martin's** "Iron Hypothesis" of ice ages. Martin suggested, before he passed away in 1993, that an increase in the flow of iron-rich dust to the ocean causes phytoplankton (single celled algae) to grow. The increased photosynthesis removes carbon dioxide from surface waters as the algae create biomass. This carbon dioxide is replaced by carbon dioxide gas that flows into the sea from the atmosphere. Reduced carbon dioxide in the atmosphere cools the planet ($CO_2$ is a greenhouse gas that warms the earth). The results of this work, funded by the National Science Foundation, the Department of Energy, and the US Coast Guard, will be a much better understanding of how biological processes may regulate climate.

Measurements of dissolved iron and the results of iron enrichment experiments show that phytoplankton growth and biomass are limited by the very small amounts of iron in seawater. About 20% of the ocean's surface waters have high nitrate (which was previously thought to limit algal growth) and low chlorophyll (we use chlorophyll to determine how much phytoplankton is present). These HNLC waters are probably iron limited. In 1995, we added iron to the HNLC waters of the equatorial Pacific and created a massive plankton bloom (**Coale et al., 1996**). Now, we're going to try the experiment in the Southern Ocean, where most of the HNLC waters are located.

We will perform two iron enrichments during the expedition, one north and one south of the Antarctic Polar Front Zone (APFZ – near 61°S) along 170°W. The region north of the APFZ has low concentrations of silicate (<3µM) with high concentrations of nitrate (>20µM). Waters south of the APFZ have high nitrate and high silicate. Diatoms are a phytoplankton that requires silicate to make a shell (called a test). Diatoms remove most of the carbon dioxide from surface waters. Although both regions have high nitrate, diatoms may not grow north of the front due to Si limitation. If diatoms don't grow north of the front, where most of the HNLC water is found, then the Iron Hypothesis may not work.

Three ships will be involved in the experiment. Each will come at a different time so that we can observe the iron fertilized patches for the longest time. The Research Vessel ROGER REVELLE from Scripps Institution of Oceanography will go first. The REVELLE team will add the iron to both the North and the South patches. After the iron and an inert chemical tracer ($SF_6$) are added, the REVELLE's primary mission is to map the size and characteristics of the South patch using a

SeaSOAR fish towed behind the ship that pumps water up to the ship. They will also be collecting samples for initial biological shipboard mapping of iron concentrations, nutrients, chlorophyll, and photosynthetic efficiency.

The R/V MELVILLE (also SIO) will sail several weeks later to arrive just as the patches are formed. The MELVILLE's team will make detailed measurements of phytoplankton physiology and rate processes. They will be taking samples daily for phytoplankton growth rates and biomass, soluble and particulate iron and zooplankton biomass. Particle interceptor traps, deployed from the R/V REVELLE, will be retrieved by the R/V MELVILLE and used to compare the amount of carbon sinking from inside and outside of the patches.

Finally, the ice breaker POLAR STAR (US Coast Guard) will arrive to assess how much carbon was removed from the iron fertilized patches. The POLAR STAR team will make carbon export estimates using the naturally occurring isotope Thorium 234 that is found throughout the ocean. (**click to see full details of this leg**)

The observations will be an essential test of the Iron Hypothesis that will allow us to form a much clearer understanding of the role that iron and phytoplankton may play in regulating the earth's climate.

| Institution | | Principal Investigator(s) |
|---|---|---|
| **Moss Landing Marine Laboratories** | MLML | Kenneth Coale |
| **Monterey Bay Aquarium Research Institute** | MBARI | Ken Johnson |
| | | Francisco Chavez |
| **Oregon State University** | OSU | Burke Hales |
| | | Jack Barth |
| **Lamont Dougherty Earth Observatory** | LDEO | Taro Takahashi |
| **Duke University** | DUKE | Richard Barber |
| **Virginia Institute of Marine Science** | VIMS | Walker Smith |
| | | Hugh Ducklow |
| **University Of Hawaii** | UH | Mike Landry |
| | | Robert Bidigare |
| **NOAA Atlantic Oceanographic and Metereological Laboratory** | NOAA-AOML | Rick Wanninkhof |
| **University of Miami** | MIAMI | Frank Millero |
| **Lawrence Berkeley National Laboratory** | **LBL/Ocean Biogeochemical Processes** | James Bishop |
| **Rutgers University** | RUTGERS | Paul Falkowski |
| **University of Massachusetts** | UMASS | Mark Altabet |
| **New Mexico Tech.** | NMT | Oliver Wingenter |
| **San Francisco State Univ. - Romberg Tiburon Center** | SFSU | William Cochlan |
| **Univ. of Calif. Santa Barbara** | UCSB | Mark Brezinski |
| **Massachusetts Inst. Of Technology** | MIT | Penny Chisolm |
| **Woods Hole Oceanographic Institution** | WHOI | Ken Buesseler |

## Details of the mission aboard the USCGC Polar Star

**Objectives**

**Does iron fertilization lead to enhanced carbon sequestration?**

The primary tenet of John Martin's original iron hypothesis, is that iron supply controls phytoplankton growth in high-nitrate low-Chlorophyll (HNLC) regions. This hypothesis has now been proven using mesoscale iron fertilization experiments in the equatorial Pacific (FeExII) and most recently in the Southern Ocean (SOIREE). However, in order for iron to have an effect on C removal and sequestration to the deep ocean, the fate of the phytoplankton carbon is paramount. At present, scientists have only a limited understanding of the consequences of long term iron fertilization scenarios, and have stated for example that : "SOIREE confirms that iron supply controls phytoplankton processes at this site in summer, but as no significant iron-increased export was observed, we could not test the second tenet of the 'iron hypothesis', which requires that fixed carbon is then sequestered in the deep ocean" (Boyd *et al.*, 2000. *Nature*, 407, 695-702).

This research proposal seeks to answer the question: **Does iron fertilization lead to enhanced carbon sequestration?** We propose to do so by extending C export measurements in time after the end of the upcoming Southern Ocean Iron Enrichment Experiment (SOFeX). These measurements are important as climate and modeling studies suggest that the Southern Ocean is a potential site for enhanced C sequestration due to the large inventory of unused nutrients and the processes for intermediate- and deep-water formation that take place in this region. Our experience in the Southern Ocean (Charette and Buesseler, 2000, *Geochem. Geophys. Geosys*., paper 2000GC000069) showed that there was no enhanced export within the 13 days time-window that we measured C fluxes during SOIREE. In addition, the astounding view from a SeaWiFS satellite image showing a large patch of chlorophyll at the SOIREE site some 5-6 weeks after the start of the experiment (see Nature cover, v407) has also led us to speculate that this Fe induced, Southern Ocean marine ecosystem must have supported very low Fe losses, and hence may not have led to significant C removal out of the surface ocean.

What's next is a plan by US scientists to return to the Southern Ocean for a more detailed study of the response of the marine ecosystem to iron fertilization. The Southern Ocean Iron Enrichment Experiment (SOFeX) is currently taking place south of New Zealand (sponsored primarily by the US National Science Foundation). Aboard the USCGC Polar Star, we will join this expedition.

**Technical Approach**

In particular, my lab will lead export studies which utilize thorium-234 as a tracer of surface ocean particle fluxes. Thorium-234 has now been widely used as a tracer of scavenging in the oceans and to calculate POC export in the upper ocean (summarized in Buesseler, 1998, *GBC* 12(2), 297-310). Thorium-234 activities are generally lower than its parent $^{238}$U activity in the upper 100-200m- the so-called $^{234}$Th "deficit"- and this deficit tends to be largest in coastal settings and during blooms. Thorium-234 fluxes on sinking particles are calculated from a knowledge of the source (from $^{238}$U decay) and loss terms ($^{234}$Th decay and sinking). In fact, by following the Fe bloom in a lagrangian fashion over time, we will obtain the most precise estimates of export since we are not constrained by unresolved physical effects on the $^{234}$Th balance, and time series samples allow for non-steady state modeling which is critical for understanding export dynamics. If the $^{234}$Th export rate can be quantified (from the $^{234}$Th activity balance), then POC or PON export fluxes via sinking particles can be determined simply by multiplying the $^{234}$Th export rate by the measured ratio of $^{234}$Th to POC or PON on sinking particles (POC flux = $^{234}$Th flux * [POC/particulate $^{234}$Th]; summarized in Buesseler, 1998).

In addition to the $^{234}$Th work, we will also sample for major geochemical (i.e. C budget- DIC, DOC, POC; nutrients; particles; metals) and biological parameters (pigments, plankton tows). We will coordinate retrieval of drifting optical and sediment trap moorings that would be left in place by the SOFeX team. These continuous measurements from moorings will be a key window into processes- including export- that take place while we are not on site, and provide for a convenient fix on the position of the patch as we try to re-occupy the site.

**Significance of proposed research**

The results thus far from two iron fertilization experiments have been stunning- large patches of the ocean turn green with increased plankton growth. But we need to know more. Essentially, it is not enough to create a plankton bloom, but you need to have the removal of plankton to the deep sea as they die or are eaten by the marine zooplankton, otherwise carbon dioxide will just "burp" back into the atmosphere as the algae decompose. ***The question of increasing the sinking flux of carbon to the deep ocean remains open***, since our studies at WHOI have indicated that the effect of iron on C removal is quite varied. One study showed large C fluxes in the equatorial Pacific, while this latest study in the Southern Ocean showed no removal (see: **http://cafethorium.whoi.edu/Fe/1999-Annualreport.html** )

The bottom line is that many scientific and public interests are coming together which propose the use of ocean iron fertilization to reverses the global greenhouse effect. Industrialists already see this as a simple and cheap engineering solution to a huge social problem. However, two important questions remaining are 1) Will it work?, and 2) What are the ecological consequences? This proposal focuses on these questions by taking advantage of the USCG icebreaker to extend in time the SOFeX study. This is a rare opportunity to join a cruise that would answer an important question on the role of Fe in carbon sequestration that has considerable scientific merit and which already has garnered significant public and business interest.

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