per square inch) in the vicinity of highly corrosive, 400°C fluids presents many engineering challenges. In addition, many organic species are gases requiring that the sampling device be gas-tight to sea-floor pressures. The sampler shown in the photo on page 21, constructed of titanium, is easily deployed using the manipulator arms of the submersible Alvin or remotely operated vehicles such as Jason. A key feature of this sampler is that it allows quantitative characterization of a single fluid in terms of both its organic and inorganic composition, something that has not been possible in the past.

In the fall of 1999 we collected high-temperature fluids (300 to 374°C) venting from basaltic rocks at the Endeavour segment of the Juan de Fuca Ridge. These fluids were extremely gas-rich, containing high concentrations of carbon dioxide, hydrogen, methane, hydrogen sulfide, and low molecular weight hydrocarbons. The bar graph shows concentrations corresponding to as much as 3 liters of gas per liter of fluid at ambient pressure conditions, causing the fluids to fizz upon removal from the pressurized sampler. The high gas content suggests that these fluids represent a vapor phase produced during boiling beneath the seafloor. The presence of substantial hydrocarbons is intriguing, considering they are present at exceedingly low levels in seawater or basalt, and may reflect abiotic synthesis in the crust or derivation from a buried sediment source that is presently not visible.

In the summer of 2000 we are scheduled to return to an area of the Juan de Fuca Ridge called Middle Valley where high sedimentation has blanketed the ridge crest with sediments. There is no question that hydrothermal fluids are reacting with both sediments and basalt at this location, and results from these efforts will form the basis for an evaluation of the role of sediment reactions at Endeavour.

Relative to unsedimented systems, the diversity of organic alteration products at Middle Valley is substantially greater due to thermal maturation of sedimentary organic matter and may even lead to the instantaneous (on a geologic time scale) generation of petroleum. Because organic alteration processes responsible for petroleum generation at Middle Valley are in many ways analogous to those occurring in conventional sedimentary basins responsible for economically viable oil deposits, the implications of this research go far beyond the study of ridge-crest hydrothermal systems. Ultimately our efforts will develop and verify new models for the description of organic transformations in subsurface aqueous environments.

### Fertilizing the Ocean with Iron

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Iron fertilization of the ocean is a hot topic not only within the ocean research community but also among ocean entrepreneurs and venture capitalists who see the potential for enhancing fisheries through large-scale ocean manipulations. In the 1980s, the late John Martin (Moss Landing Marine Laboratory) advanced the idea that carbon uptake during plankton photosynthesis in many regions of the world's surface ocean was limited not by light or the major nutrients nitrogen or phosphorus but rather by a lack of the trace metal iron, which is typically added to the open ocean as a component of dust particles. Laboratory experiments and correlations between dust and atmospheric carbon dioxide levels in ancient ice core records suggested that the ocean would respond to natural changes in iron inputs by increasing carbon uptake and hence decreasing atmospheric carbon dioxide, thus altering the greenhouse gas balance and climate of the earth. Martin once dramatically said: “Give me half a tanker full of iron and I’ll give you an ice age.”

In two 1990s experiments, US investigators led by Ken Coale (Moss Landing Marine Laboratory) purposely “fertilized” a large patch of water near the equatorial Pacific with iron. The results showed a strong biological response and a chemical drawdown of carbon dioxide in the water column.

But what was the fate of this carbon? We know that plant uptake of carbon in the ocean is generally followed by a zooplankton bloom as grazers respond to the increased food supply. These populations then produce a blizzard of marine snow, as fecal pellets and other particles descend through the water column, carrying or “exporting” their carbon load to the deep sea in
a process known as the “biological pump.” Drawing on many years’ experience working with thorium in seawater, my laboratory colleagues and I are studying the decrease in surface water thorium following iron fertilization as a proxy for carbon export from the surface to the deep sea. Thorium is a naturally occurring element that by its chemical nature is “sticky,” and, due to its natural radioactive properties, relatively easy to measure.

Analysis of a series of seven surface water samples, collected during a 1995 experiment called FeExII, told us that, indeed, as iron was added and plant biomass (measured as chlorophyll) increased, there was a corresponding decrease in total thorium levels. We used the measured thorium decrease to quantify the increase in particulate organic carbon export as particles sank out of the surface layer (upper graph below), noting an interesting delay between the uptake of carbon by the plants and its export as sinking particulate organic carbon. We also noted that the relationship between uptake and export was not 1:1, but rather the iron-stimulated biological community showed very high ratios of export relative to carbon uptake. Thus by the end of the experiment, the efficiency of the biological pump had increased dramatically.

However, results of a similar iron fertilization experiment led by Phil Boyd (University of Otago, New Zealand) during the 1999 summer season in waters south of Australia were very different. The biological response was much slower and less dramatic, and total thorium levels never responded, indicating that the biological pump was not activated (lower graph). We speculate that the difference is due to the colder waters and the resulting slowness of the biological community’s response to stimulation. Whether the biological pump turned on after we left the site is a more complicated question, but for now we cannot say that simply adding iron to these waters will result in enhanced removal of atmospheric carbon dioxide to the deep ocean.

The delays in export after an iron-stimulated bloom fits with some of our recent thorium studies in natural systems in the Arabian Sea and in waters around Antarctica. Further work on the effects of iron fertilization in Antarctic waters is scheduled for early 2002. This time we hope to follow the response for 20 to 30 days with a large team of US scientists. In the meantime, the pressure to try something on an industrial scale is mounting and likely to take place with or without scientific input as entrepreneurs gather permits and patent processes for fertilizing the ocean with iron on a large scale.

For example, the territorial waters of the Marshall Islands have been leased to conduct an iron fertilization experiment. The new businesses involved suggest that the iron fertilization process will reduce atmospheric carbon dioxide levels, allowing the Marshall Islands (and other island countries) to profit by trading carbon credits with more industrialized nations. They also point to increased fisheries as a consequence of enhanced iron levels. Prior to these large scale manipulations, more dialogue is needed between these commercial interests, economists, national governments with a marine interest, climate modellers, fisheries biologists, and ocean scientists. While dumping iron may not produce an ice age, it is likely to alter the ocean in unforeseen ways. Whether we end up with productive fisheries and lower carbon dioxide levels, or a polluted ocean with new opportunistic species that do not support enhanced fisheries, is unknown.