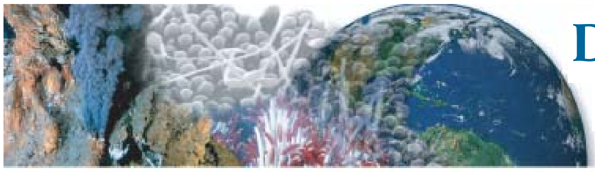
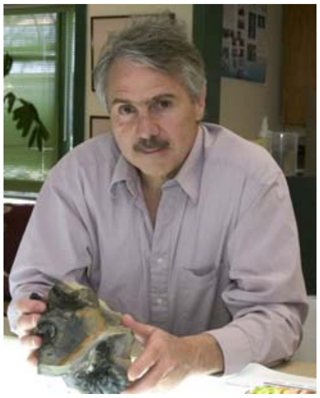


Deep Ocean Exploration Institute

INVESTIGATING EARTH'S DYNAMIC PROCESSES

Report ~ Summer 2005

Message from DOEI Director Dan Fornari



The Earth and oceans with their myriad interactions are a puzzle. For millennia, humans have been trying to unravel the intricate web of physical, chemical and biological processes that control the earth-ocean system. The past century has seen revolutionary progress on many scientific fronts involving earth and ocean sciences, but our detailed knowledge of the connections between multidisciplinary processes is still hampered. Two key reasons are inaccessibility to remote parts of the planet and the need to explore and measure Earth's ever-changing dynamics over both vast and minute time spans.

The imperatives for investigating the earth-ocean system are significant. The Sumatran earthquake of December 2004 and the devastating tsunami it generated are prime examples of why a better understanding of the integral relationship between earth and ocean is essential. Through that knowledge will come applications that can help save lives and improve economic conditions for millions.

The physical processes that shape our planet impact a diversity of chemical and biological events, which currently appear to be unique to Earth. The agenda of the Deep Ocean Exploration Institute (DOEI) is to explore remote parts of the ocean and Earth, using innovative technologies that provide new perspectives.

DOEI Research

DOEI research covers a broad disciplinary range that includes microbial studies related to life in extreme environments, mantle melt formation, earthquake mechanics and volcanic eruptions, as well as the development of various technologies needed to study these processes. The three articles highlighted in this report describe some of our current research. They represent just a portion of DOEI's full scientific agenda.

Wolfgang Bach and colleagues summarize the Deep Biosphere – Dark Energy Workshop held at WHOI in Fall 2004. The compelling questions and approaches discussed in the report will guide biogeochemical and microbiological research in the deep ocean and Earth for the coming decades. Clues to the origin and evolution of early life may be revealed.

Craig Taylor and Steve Molyneaux's microbiological sampler is an innovative technology created at WHOI to explore the complex biological and geochemical processes taking place in the deep biosphere.

The report by Rob Reves-Sohn and Al Bradley on a new sensor for underwater vehicles describes a clever approach to applying existing technology to a persistent problem in deep ocean sensing – How do you "see" out into the murky unlit waters of the deep ocean? Rob's and Al's new green laser sensor has the potential to revolutionize how we conduct deep-sea surveys and explore remote areas of the global ocean.

These efforts and the research undertaken by numerous other investigators supported by DOEI illustrate how scientific progress is enabled by the Ocean Institutes. By providing much needed seed money, which leverages and matches grants garnered by WHOI scientists from federal agencies, DOEI is helping to build the foundation for ever-stronger multidisciplinary programs at the Institution.

Deep Ocean Exploration Institute
www.whoi.edu/institutes/doei

Editor: Alison T. Kline

Energy in the Dark: Life in the Deep Ocean and Beyond

(Based on an article submitted to *Eos*, a weekly newspaper published by the American Geophysical Union)

Wolfgang Bach and **Katrina Edwards**, Marine Chemistry & Geochemistry,
John Hayes, Geology & Geophysics,
Stefan Sievert, Biology,
(all at WHOI) with
Julie Huber and **Mitch Sogin**, Marine Biological Laboratory

To most people, the "biosphere" begins with green plants, and everything in it is part of a food chain that depends on energy initially captured and packaged by photosynthesis. Most geoscientists, however, are aware that this view is too restrictive. A significant portion of the organic material in the food web *does not* derive from algae or from consumers dependent on them. Substantial populations of microorganisms get along without help from the photosynthetically based food chain. They don't need any of its energy or products, not even the oxygen.

Between this solar-independent life and the conventional food chain, lies a wonderland of physical habitats and biogeochemical niches in which microorganisms catalyze chemical reactions, capture a portion of the energy, and get on with their lives. Flows of energy, of oxidizing and reducing power, and of nutrients are interwoven so intricately that the system can only be described as a web. And most of it takes place in the dark.

How, *exactly*, does all of this fit together? Based on research in the last dozen years, there is both direct and indirect evidence for bacterial life in the deep ocean, in deeply buried sediments, and within oceanic crustal rocks and fluids. The biomass in this "deep biosphere" possibly rivals the total biomass in surface-terrestrial and oceanic ecosystems. That's a lot of life.

Geochemical menus vary drastically among dark, oceanic habitats. That chemical diversity is matched by the diversity of microorganisms able to catalyze chemical reactions and exploit the energy released.

How are the mass and energy cycles of geological and biological systems in the deep ocean and subseafloor related? Solving this rich and compelling scientific problem requires an integrated approach.

First-order questions are still being explored: Who is there? How many are there? What do they do? We do not understand the evolutionary underpinnings of biogeochemical cycles in different environments. We do not know the minimal energy requirements for maintenance and growth. In approaching these questions, we must examine not only extreme environments but also the more mundane settings in the ocean.

Limitations

Shortcomings in our current knowledge have multiple origins. One is the poor success in cultivation of microorganisms from subsurface habitats. As a result, both physiological and genomic information is lagging. Geochemically, we struggle to describe the composition of deep-ocean environments at relevant spatial scales.

In general, it is hard to make chemical and biological measurements of rates and activities at the seafloor. One problem is sample size. While the characterization of microenvironments requires microsensor or microsampler work, many molecular methods require relatively high amounts of nucleic acids, which are not readily available from geological samples (e.g., drill cores of oceanic crust). Further, biomarker work at depth and high pressure is undeveloped, and a compilation of the properties of relevantly-categorized genes as biomarkers is yet to come.

New Approaches

To unravel the factors that govern the distribution and physiology of microbial species in dark environments, lines of evidence from a variety of fields can be used. Bio-medicine, genomics, biochemistry and geochemistry provide techniques to examine: genotypes and patterns of gene expression, mixed and pure cultures, isotopic distributions, distributions of biomarker lipids, and inorganic geochemical data. Convergence of these indicators will be essential to understanding the dark biosphere.

The promise of molecular and genomic tools will be fulfilled only if they are applied in well-defined microbiological, geochemical, and geological contexts. Genomic and biomarker studies could identify signals characteristic of organisms unique to the subsurface. Increased numbers of cultured representatives will improve the chance of identifying key species.

Advances in our understanding of the geochemistry and biology of the deep ocean will benefit from careful coordination between theory, experiments, and observation. Chemical and biological measurements should be made on the same spatial and temporal scales. Empirical determination of relationships between biomass and activity will be required for better theoretical predictions of biomass production.

Deep sea chemical measurements and (molecular) biological and biomarker analyses can be combined to prospect for life forms that depend on geochemical energy in the dark ocean. A theoretical framework providing links between geochemical energy supplies and microbial energy demands has already been developed. But more data and better knowledge of energy requirements for growth and maintenance of cells are required.

Although we know very little about the distribution and physiology of the environmentally significant microorganisms living in dark oceanic environments, the developments and approaches foreseen here will allow us to address essential ecological and evolutionary questions in the future.

Developing a New Microbial Sampler and Incubator for Deep-Sea Biochemical Research

Craig D. Taylor and
Stephen J. Molyneaux,
Biology Department

A variety of microbial communities inhabit the upper ocean crust. This potentially important "subseafloor biosphere" is largely unexplored, due to its inaccessibility. Major questions remain regarding the composition of oceanic microbial communities, the metabolic pathways at work, and chemistry of the crust and the fluids in this environment.

By drilling through seafloor sediments and into the crust, the Ocean Drilling Program (ODP) has created a series of Borehole Observatories to study the subseafloor biosphere (figure right). Scientists now have access to several hydrothermal environments of differing age and chemistry.

However, accurately assessing the genetic diversity of microorganisms in the crust is limited by the possibility that the samples taken from ODP boreholes may be contaminated. Fluids in which the microbes live may be altered during their ascent up the roughly 400-meter steel-cased borehole. It is also possible that borehole samples could contain microbes or other contaminants associated with the borehole itself rather than the ocean crust.

To address this problem, a miniaturized sampling and microbe-incubating apparatus, the Downhole Sampler/ Incubator (DSI), is being developed at WHOI with NSF funding (in collaboration with engineers, Fredrick Thwaites and Stephen Liberatore at WHOI, and Jim Cowen at the University of Hawaii).

With DOEI funding, a prototype of an apparatus that simulates the ODP borehole was constructed, and we are testing the ability of the DSI to obtain

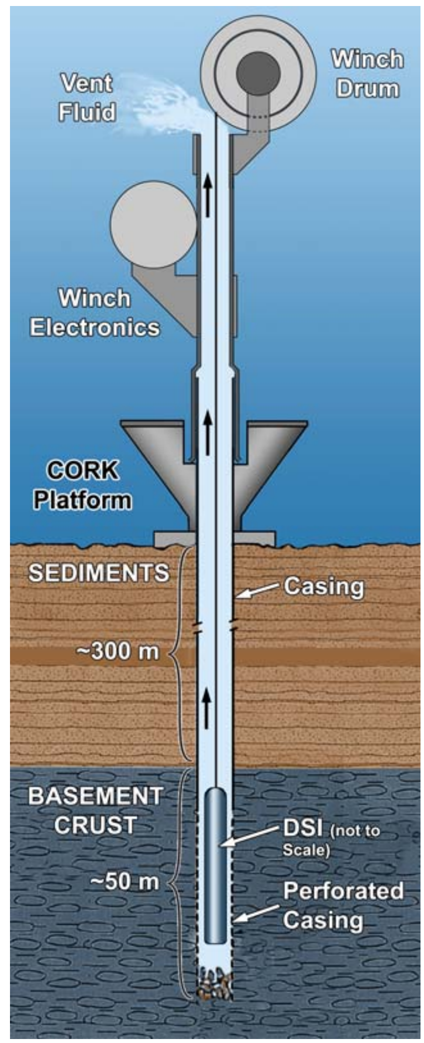


Image credit: Craig Taylor, WHOI, and James Cowen, U. Hawaii

Borehole Observatory with the DSI (Downhole Sampler/ Incubator) deployed in the upper ocean crust. The DSI device, which is currently in development, will allow non-contaminated samples of microbes to be obtained from borehole fluids in the oceanic crust.

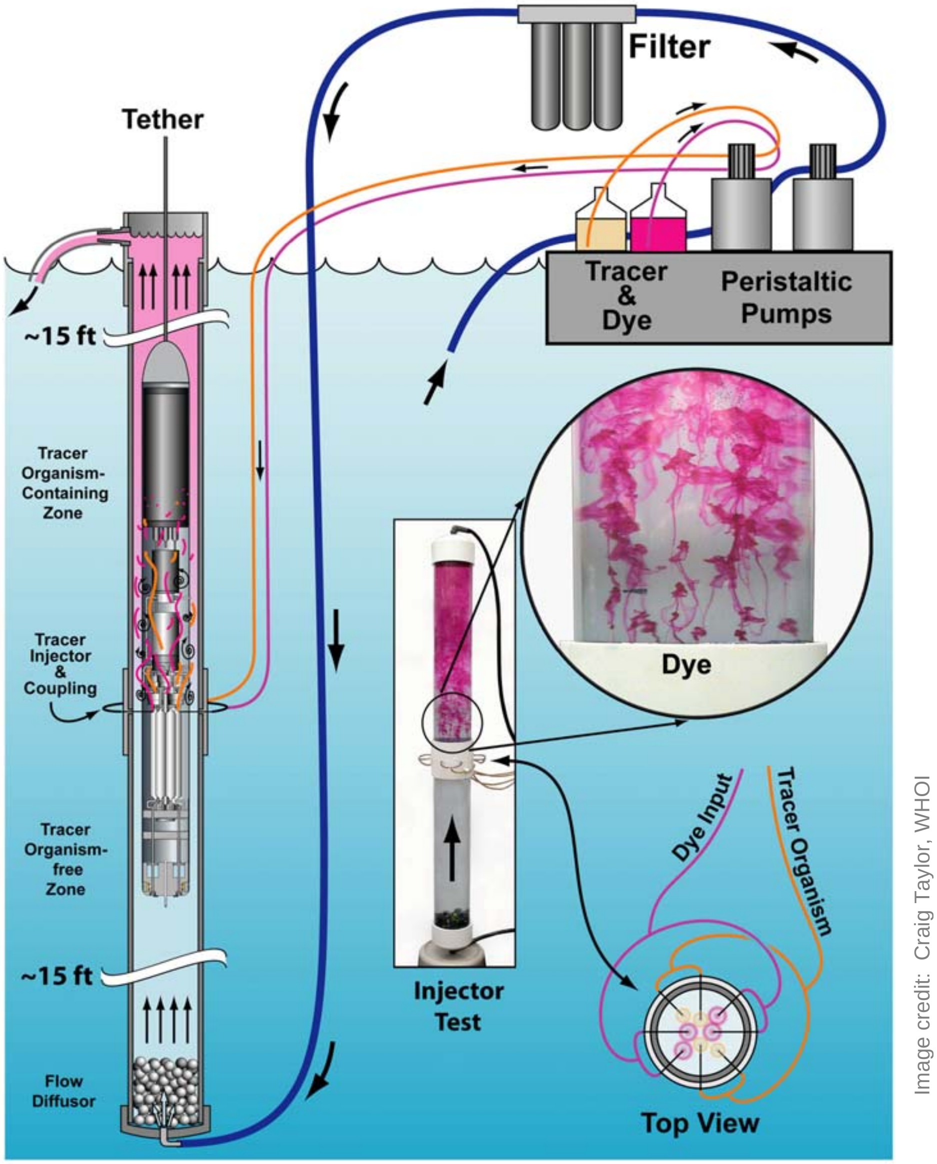
samples that are free from contamination by microbes that may exist in the upper reaches of boreholes (figure below).

To test the device, a steady flow of filtered seawater is introduced into the base of the test device via a diffuser made from glass marbles. The diffuser produces a streamlined flow of seawater up the pipe, eventually flowing past a tracer injector, where a dye and a non-virulent, red-pigmented tracer organism, *Serratia marinorubra*, is introduced via a peristaltic, or metered pump.

At steady state, the upwardly flowing seawater results in a "tracer organism-free" lower zone and an upper zone that is "contaminated" by the introduced tracer organism. The dye provides a visual indication of the behavior of the tracer in the flowing seawater. The dye and tracer are transported upward, as tendrils (see inset), until about half way up the 2-foot length of tubing, where they are gently mixed with the flowing seawater. The lower section of the pre-sterilized test apparatus has sampling ports to confirm that the lower "tracer-free" zone is indeed free of *Serratia marinorubra*.

Results of an early experiment have demonstrated that the apparatus to be employed in future testing of the DSI will work as intended. The tracer injector nozzle was exposed to contamination levels 10,000 times higher than it would experience in a typical borehole. Even then, only a single *Serratia* colony, in three samples taken, was able to penetrate the nozzle's protective barrier. Subsequent experiments, where the nozzle was exposed to contamination levels consistent with the borehole environment revealed no contamination in the lower zone.

The device successfully provides for controlled exposures to contamination, while simultaneously maintaining a completely "tracer organism-free" zone. This ensures the ability of the DSI to obtain reliable samples from deep subseafloor boreholes.



Apparatus used to test the ability of the Downhole Sampler/Incubator (DSI) to acquire pure, untainted samples of microbes living in the ocean crust. The red-pigmented dye (inset) provides a visual indication of the behavior of a tracer organism injected into the borehole fluids during experiments. Even though the tracer injector nozzle is exposed to heavy contamination during experiments, the protective cap system designed to prevent sample contamination worked effectively, thus ensuring the DSI's future reliability.

Using AUVs with Lasers to Detect Hydrothermal Vent Plumes in the Deep Sea

Rob Reves-Sohn, Geology & Geophysics
Al Bradley, Applied Ocean Physics & Engineering

In the past decade, free-swimming autonomous underwater vehicles (AUVs) have been making the transition from research and development projects to reliable operational assets that support a wide range of interdisciplinary science. The scientific products generated by AUVs were once limited by technical challenges associated with basic operational considerations (e.g., vehicle navigation, battery duration, etc.), but now AUVs have matured to a point where major limitations are primarily those associated with the sophistication and utility of the onboard sensors.

Significant advances have been made in the adaptation and miniaturization of widely used oceanographic sensors for AUV platforms. Most operational AUVs now carry low-power versions of fundamental instruments such as conductivity/temperature/depth sensors, bathymetric sonars, current meters, magnetometers, etc.

Importantly, AUVs have influenced a paradigm shift in the approach to certain types of marine science. AUVs allow for high spatial resolution surveys that were not previously feasible with towed instruments, particularly in the deep ocean, where the dynamics of passively towing instrumentation behind several kilometers of cable precludes any sort of precise sensor positioning.

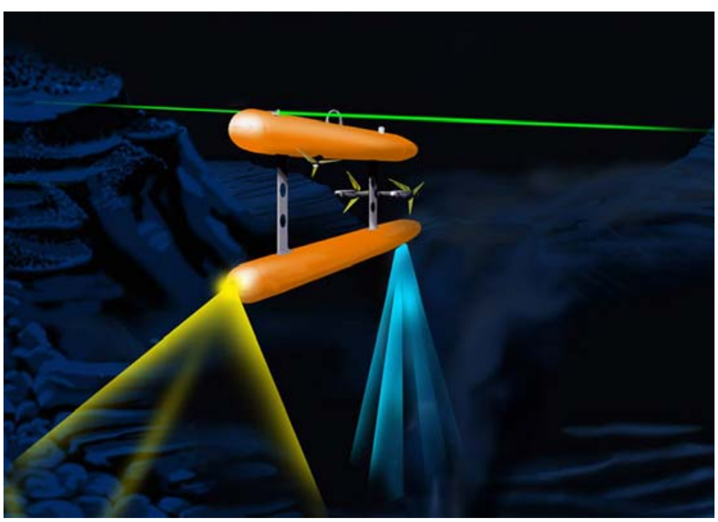
The search for hydrothermal plumes at deep-sea vent fields is one type of survey mission presently undergoing a revolution as a result of the new capabilities offered by AUVs. Successes have been demonstrated repeatedly over the past few years by WHOI's Autonomous Benthic Explorer (ABE) in surveys of the Mid-Atlantic Ridge, East Pacific Rise, Juan de Fuca Ridge and the Lau Basin in the Pacific.

Hydrothermal plume detection by optical backscatter (OBS) is a highly effective component of a suite of plume detection techniques currently used on AUV platforms. Hydrothermal fluids are rich in particulates, which are readily detected by OBS sensors that measure the optical clarity, or "cloudiness" of a volume of water right next to the vehicle. But the restricted range of the OBS sensor requires that the vehicle swim directly through a plume to detect it – a major shortcoming in the vast ocean.

With funding from DOEI, we have designed and completed preliminarily testing of a new OBS instrument capable of detecting a plume several tens of meters to either side of a vehicle, effectively allowing it to "see" a plume in the distance. The design uses a green laser to illuminate a beam of water projecting to each side of the vehicle. An optical detector system at the aft end of the vehicle measures the intensity of the light scattered from a plume along the beams (figure below).

While this technology will prove universally useful to hydrothermal vent research, it is essential for plume mapping in challenging environments, such as under Arctic ice, where using an AUV is the only feasible survey method. Most importantly, it will allow systematic and robust searches for plume sources from an AUV platform. This stand-alone AUV capability will be essential to the success of a NASA- and NSF-funded Arctic initiative that involves several researchers at WHOI (Reves-Sohn, Bradley, Singh, Yoerger, Shank, Humphris) in cooperation with the University of Maryland.

Image credit: Paul Oberlander, WHOI

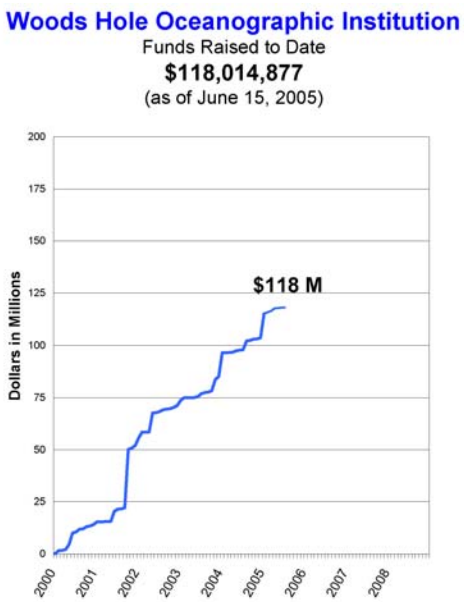


AUV Puma (short for "plume mapper"), currently in development. The green swath laser mounted on top projects a few tens of meters to either side of the vehicle, illuminating particulate matter that emanates from hydrothermal vents. Optical backscatter effectively allows Puma to "see" a vent plume in the distance.

Financial Information

Fundraising Campaign

Progress on our $200 million campaign to endow the four Ocean Institutes and Access to the Sea Program continues on pace. As of June 15, 2005, WHOI had raised $118,014,877 in new gifts from many generous individuals, foundations and corporations. These funds support the varied activities and innovative research projects carried out under the auspices of the Institutes.



For example, the work of DOEI Fellow Dana Yoerger on AUVs, in collaboration with colleagues in WHOI's Deep Submergence Lab and elsewhere, led to funding by the National Science Foundation for a hybrid remotely operated vehicle (HROV), designed to reach the deepest depths of the ocean – 11,000 meters. This $5 million project will provide unprecedented advances in deep ocean vehicle technologies – including micro-fiber cable systems, ceramic pressure housings, lighting and robotics control systems – that will revolutionize how we map, image and sample remote and deep ocean terrains.

Another DOEI Fellow, Meg Tivey, has several federally-funded field projects using the ROV *Jason II* to study the hydrothermal vents in regions such as the Mid-Atlantic Ridge, Central Indian Ridge, and the Lau Basin in the Pacific. Meg's role as a DOEI fellow has provided her the opportunity to explore a range of new technical avenues, including developing innovative temperature and chemical sensors for on site measurements at vent sites. Her fellowship has also enabled her to develop hypotheses and collaborate with a range of scientists to carry out research on hydrothermal vent mineralogy and related systems. Total science and ship time funding for Tivey's projects is on the order of $2.5 million.

Allocation of DOEI Funds

Through an internal peer-review process, DOEI's Institute Advisory Committee recommends the projects and personnel to be funded each year.

Between 2001 and 2005, DOEI supported six fellows, three postdocs, three graduate students and 26 research investigators from four different WHOI departments. In addition, DOEI hosts the Geodynamics Seminar series, the Dive and Discover Web site, and held three in-depth workshops for scientists.

Total investment in the work of DOEI thus far is $3,200,357. This support is critical to continued WHOI leadership in the earth and ocean sciences and the engineering development needed to access "inner space."

DOEI Leveraging

The Deep Ocean Exploration Institute serves a critical role in fostering cross-disciplinary scientific inquiry and facilitating engineering advances that enable new discoveries. The past four and a half years of DOEI-sponsored science provide numerous examples of our success in leveraging federal funds to advance our programs – on average a sevenfold increase over our original investment.