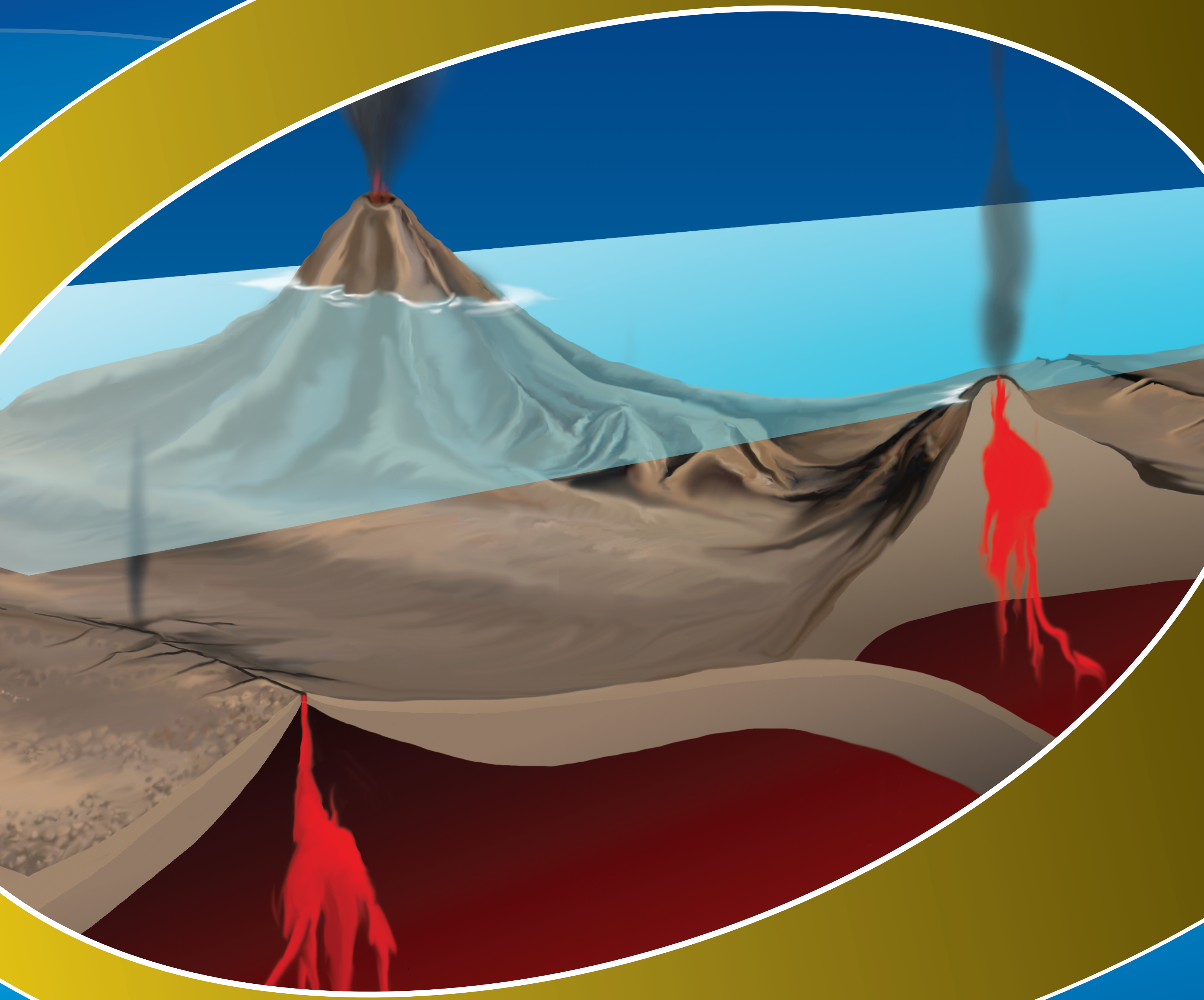


Deep Ocean Exploration Institute

Summer 2009 Report

Woods Hole Oceanographic Institution

Message from the DOEI Director


Photo of Meg Tivey by Tom Kleindinst, WHOI

The deep ocean is diverse—it is highly dynamic near plate boundaries where ocean crust is created or consumed but quiescent in most areas far from plate boundaries where sediments have accumulated over millions of years. Access to the deep sea is difficult, requiring technologies that allow us to observe, measure, and sample material that lies thousands of feet beneath the ocean's surface.

The goal of the Deep Ocean Exploration Institute (DOEI) is to increase our understanding of the wide range of geological, chemical, physical, and biological processes occurring in the deep ocean, and in Earth's interior. A key feature of the DOEI is its emphasis on fostering the development and use of advanced technologies to access remote parts of the planet, allow more efficient data collection, and make measurements of greater precision and accuracy.

Many of the research projects funded by DOEI over the past year combine exploration with the use of new techniques, and four are presented in this issue. DOEI fellow, biologist Tim Shank has been using genetic techniques to examine the role that seamounts (undersea mountains) play in controlling the biodiversity and biogeography of species associated with deep-sea coral ecosystems and their conservation. Geologists Alison Shaw and postdoctoral fellow Nicole Keller are analyzing volcanic material—gases and erupted rocks from land-based and submarine volcanoes—to understand where sulfur present in volcanic gases comes from, and how it moves between Earth's mantle, ocean and atmosphere.

Advances in technology have also been central to DOEI post-doctoral fellow James Kinsey's research into the feasibility of measuring gravity in the deep-sea from autonomous underwater vehicles (AUVs). Recent improvements in navigation make this possible, and this ability could significantly increase the number of gravity measurements that can be made, providing information about the density and porosity of the shallow ocean crust. Joint Program student Kevin Richberg, working with his advisor Stefan Sievert, is exploring the sub-seafloor biosphere. They are using two different techniques to identify chemoautotrophic microbes—organisms that are primary producers and acquire energy not from the sun, but from interactions of ocean water with inorganic compounds present in warm seafloor vent fluids.

In addition to providing funds for research, DOEI continues to play important roles in WHOI's education and outreach efforts. The Geodynamics Seminar Series topic for 2008 was "Subduction From Trench to Arc," and in 2009 was "Climate Change: Forcing, Responses and Geo-engineering." Recent outreach efforts included providing support for an international science and policy workshop on deep-sea mining. The workshop preceded a Morss Colloquium on "Precious Metals from Deep-Sea Vents" organized by DOEI fellow Maurice Tivey. And a new WHOI cross-disciplinary initiative was launched this year—the Ocean Ridge Initiative—focused on exploring the mid-ocean ridge system, the largest continuous geologic feature on Earth.

We invite you to visit our Web site (www.whoi.edu/institutes/doei) to learn more about DOEI activities. We are grateful for your support of WHOI and the Deep Ocean Exploration Institute. It greatly enhances our ability to explore remote areas of our planet and better understand Earth and ocean processes.

—Meg Tivey

Seamount Investigations

Challenging Paradigms and Informing Conservation

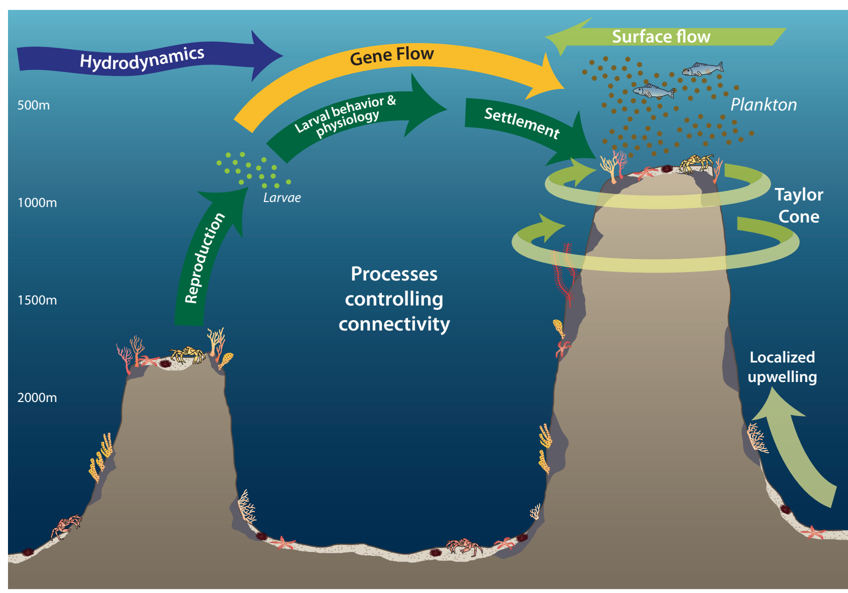
Submarine volcanic ridges and seamount chains, present in all ocean basins, provide stepping-stone habitats that are likely to have a fundamental impact on the dispersal and evolution of marine life. With my DOEI Fellowship, I am investigating the evolutionary processes that impact the diversity of deep-sea fauna (animals). Specific studies are aimed at understanding the formative role seamounts play in controlling the variety and placement of deep-sea coral and the high diversity of species they host.

A key component of my research involves understanding the mechanisms that maintain species across ocean basins, and how geographic separation, depth differences, and circulation patterns around isolated marine habitats impact animal migration and the connection between contemporary (or modern day) genetic pools. I am pursuing genetic research that challenges current seamount paradigms, including the belief that seamounts isolate populations, generate new species, and serve as havens for once abundant, now relict species.

I have also initiated a Barcode of Life project for seamount fauna. The Seamount Barcoding Association is a global effort to coordinate the assembly of a standardized reference DNA sequence library for seamount fauna. The benefits of this barcoding effort include: 1) facilitating rapid field identification of species for all potential users, including resource managers; 2) rapidly highlighting new or previously unrecognized species; and 3) recognizing the presence of potentially threatened or managed species for conservation and protection of ocean resources. Of particular interest in this initiative is the ability of corals to harbor a diverse array of associated species, including commercially important fish species.

My focus is on natural processes—how discrete seamount populations are connected—but the insights from this research are critical for understanding potential anthropogenic disturbance to deep-sea populations. Seamount ecosystems around the world are currently threatened by destructive mining and fishery practices (e.g., trawling and long-lining), emphasizing the need for greater understanding of the processes affecting uncharacterized species and populations in these habitats. Conservation managers are trying to manage and protect coral areas to stem the loss of this biodiversity. Through my fellowship, I am providing important insights into how these species are maintained through dispersal and genetic connectivity to managers concerned with the protection of oceanic biodiversity, and guiding management and protection of these valuable resources in our deep ocean.

—Timothy Shank



Tim Shank/Jack Cook, Woods Hole Oceanographic Institution

The key factors that affect the genetic connectivity of populations and species between seamounts. Seafloor geologic features such as seamounts may provide critical stepping-stones or isolating barriers to fauna and their larvae to cross deep areas of the oceans. The availability of suitable habitat, larval dispersal and settlement, and hydrographic conditions around seamounts are just a few of the factors that can promote or impede the successful connectivity of populations (and the subsequent conservation and management of ecosystems) in the deep ocean.

The Sulfur Cycle

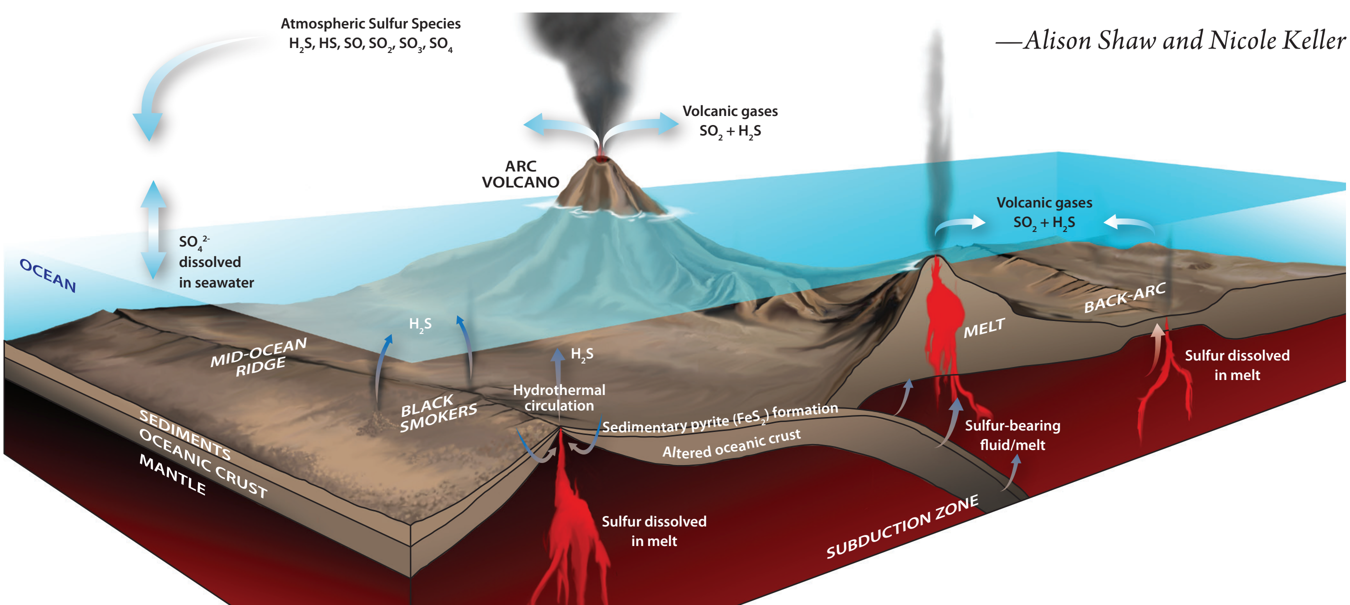
Tracking sulfur through volcanic systems to the oceans and atmosphere

Sulfur is an important element that plays crucial roles in climate variability, ocean chemistry, and biological activity. It is exchanged between the atmosphere and the oceans and is removed from the oceans into the seafloor via alteration of the oceanic crust, sedimentation and microbial processes. The sulfur stored in the crust is recycled into the mantle at subduction zones, where oceanic crust dehydrates as it descends to great depths. Sulfur and other volatiles are released from the subducting crust into the overlying mantle as the crust reaches higher temperatures and pressures. The presence of these volatiles lowers the melting temperature of the mantle and leads to volcanism, with volcanoes forming in "arcs" and with further volcanism occurring behind the arc, in what is termed a back-arc basin. These volcanoes pump large quantities of sulfur back into the atmosphere and the oceans by passive degassing (venting) or eruptive activity. Large volcanic eruptions can lead to climate change due to an increase in sulfur gases in the atmosphere.

Despite its relevance, the mechanism and extent of sulfur cycling through subduction systems remains largely elusive. Our DOEI-funded study addresses this mystery using samples from active land-based volcanoes in Costa Rica, and submarine volcanoes in the Lau back-arc basin (SW Pacific). Our strategy is to track how sulfur moves through subduction zones by targeting processes that fractionate sulfur isotopes (separate atoms of sulfur that have different numbers of neutrons and thus different atomic mass). In Costa Rica, we collected volcanic gases by inserting a titanium tube into a degassing vent and running the gas sample through chemical filters that trap the sulfur present in the gas. We also collected erupted rocks, which contain minerals that formed in the magma chamber and that trapped some magma as a "melt inclusion." Analyses of melt inclusions give us the sulfur isotope composition of the magma chamber. Comparing this with the isotopic composition of volcanic gases allows us to evaluate whether degassing processes change the isotopic composition of sulfur. In the Lau Basin, erupting lavas chill very quickly, forming glass. Isotope analyses of this glass (partially-degassed lava) can be compared to isotope analyses of melt inclusions (undegassed material) to estimate to what extent the process of degassing affects the sulfur isotope values as the lava rises to the seafloor. If the values are the same, then degassing has no significant effect on sulfur isotopes, and the values thus reflect the source magma.

This work on determining sulfur isotope compositions of mantle material, gas, and glass is essential for understanding how sulfur behaves in subduction zones and volcanic systems, important parts of the global sulfur cycle and Earth's climate and biological systems.

—Alison Shaw and Nicole Keller

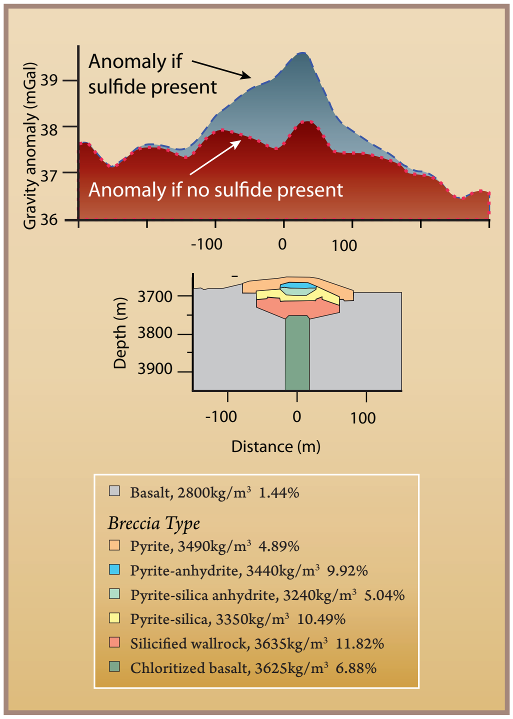


Gravity Measurements

Understanding the Structure of Shallow Oceanic Crust

Gravity measurements provide valuable information about the density and porosity of the sub-seafloor that can help us to better understand its structure. For example, gravity can be used to determine the size of potentially valuable metal-rich massive sulfide deposits on the seafloor. Currently, near-bottom gravity surveys primarily use on-bottom gravity measurements—where an instrument, or an instrument on a submersible, sits in a stationary position on the seafloor while obtaining data. These on-bottom measurements, while highly accurate, are time consuming. On a single dive, typically less than 10 measurements can be made.

The number of measurements could be significantly increased with continuous surveying; i.e., with gravity measured from a moving submersible operating near the seafloor. However this technique has been impractical because it requires *(i)* minimizing the vehicle's vertical and rotational motions; and *(ii)* obtaining accurate estimates of the residual vertical and rotational motion so that contributions from these motions can be subtracted from the gravity measurements.



The larger gravity anomaly that would be measured from a moving AUV above a sulfide-rich mound similar in composition and size to an active mound (blue dashed line) compared to the lesser anomaly for a crust composed only of basalt (red dashed line). Densities and porosities assumed for each mound layer are shown. The sub-seafloor structure (shown below the anomalies) is a simplified version of Ocean Drilling Program results for the active TAG mound (from Humphris et al., Nature, *1995).*

My DOEI-supported research investigates the use of autonomous underwater vehicles (AUVs) to measure the gravity effect of density anomalies (such as metal-rich sulfide deposits) occurring within the seafloor. AUVs possess two advantages over other submersibles: precision depth control (to within 0.02 meters) and highly stable attitude performance (on the order of 0.1°), thus satisfying condition *(i)*. Challenge *(ii)*—accurately estimating the vehicle accelerations—requires exploiting recent advances in navigation sensing and research into improved algorithms (mathematical formulas) for navigating AUVs.

To demonstrate our ability to measure gravity from AUVs, we developed a computer model of an active hydrothermal mound, creating a simplified depiction of its known sub-seafloor density structure. Using this depiction and actual dynamics data from the *Sentry* AUV, we computed synthesized gravimeter measurements that contain both the synthesized gravity measurements and the vehicle accelerations.

The next step was to see if a simple gravity filtering technique could be used on the synthesized AUV gravimeter measurements to remove the vehicle accelerations. While generation of the synthetic gravity measurements used precise information about vehicle depth, rotation and accelerations, the filtering technique considers current best estimates of vehicle accelerations given current abilities in navigation sensing.

Our results show that, using a simple gravity filtering technique, we can observe the increased gravity anomaly resulting from the dense sulfide minerals within the hydrothermal mound. Obtaining high-resolution gravity measurements in a cost- and time-effective manner could provide crucial information on the structure of shallow oceanic crust that is currently unavailable.

—*James Kinsey*

The Sub-Seafloor Biosphere

Identifying Primary Producers

Chemoautotrophic microbes are organisms that are primary producers and acquire energy not from the sun, but from the oxidation of inorganic compounds, and they are able to use inorganic carbon as the source for cell carbon. These organisms form the base of the food chain within deep-sea hydrothermal vent ecosystems that operate in continuous darkness. Yet, we know almost nothing about the actual activities of these microbes, the rates of the processes they catalyze, or their physiology and metabolic abilities.

My research focus is on the major microbial players involved in subsurface biomass production at deep-sea hydrothermal vents. My advisor, Stefan Sievert, and I are attempting to better understand the ecology and biogeochemical significance of chemoautotrophic microbes using carefully designed experiments.

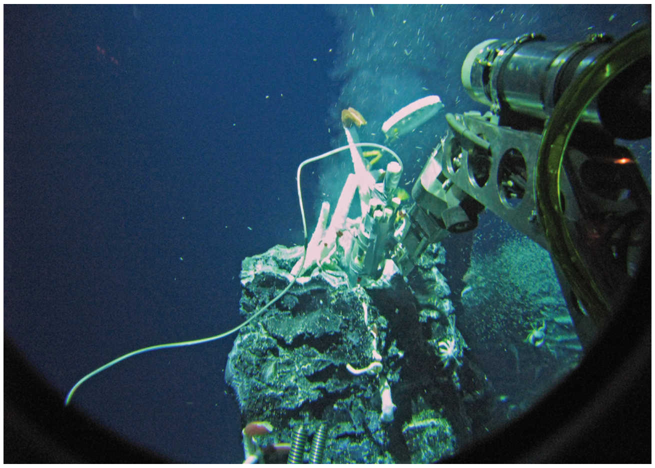
To identify chemoautotrophic microbes we are using two techniques that are based on the incorporation of carbon. We use ^{13}C-labeled compounds to link the identity of the microbes with their function. After recovering hydrothermal fluids from two warm fluid vents at the 9˚N deep-sea hydrothermal vent field on the East Pacific Rise (EPR), I incubated microbes for several days with ^{13}C-labeled bicarbonate (HCO_3^-). Following the incubations, the microbial cells were collected on filters for immediate study or preserved for subsequent microscopic analyses.

The next steps to be taken with the filtered material are to extract DNA, and then use a technique called Stable Isotope Probing (SIP) to separate "heavy" DNA, representing primary producers (autotrophs) that have incorporated the 'heavy' ^{13}C, from 'light' DNA, representing organisms that are unable to 'fix' the 'heavy' labeled inorganic carbon (heterotrophs). Subsequently, molecular methods based on the extracted DNA will be used to examine functional key genes that are indicative of specific metabolic pathways, like carbon fixation and various energy generating pathways.

A second technique, nano-scale Secondary Ion Mass Spectrometry (nano-SIMS), will be used on the preserved cells. In SIMS, a sample is bombarded by a beam of heavy particles, charged particles (Secondary Ions) are ejected and collected, then specific ions are isolated, and detected. NanoSIMS allows analyses to be done on very small areas or volumes (50-150nm). Using NanoSIMS in combination with halogen-labeled nucleic acid probes (so-called Halogen In Situ Hybridization- Secondary Ion Mass Spectroscopy or HISH-SIMS), it is possible to simultaneously determine the metabolically active cells, i.e., the cells that have taken up ^{13}C, due to their isotopic signature, and to determine what kind of bacteria or archaea have taken up the label. This allows us to link identity with function.

These studies will aid us in gaining a more comprehensive understanding of autotrophic processes at deep-sea hydrothermal vents. This project will also provide critical information to better constrain the potential importance of the sub-seafloor biosphere as a contributory factor to the overall productivity and functioning of deep-sea hydrothermal vents.

—Kevin Richberg



"Crab spa," one of the two diffuse flow vents sampled at 9˚N on the East Pacific Rise.

Precious Metals from Deep-Sea Vents

As part of his Fellow activities, Maurice Tivey chaired an InterRidge interdisciplinary working group on Seafloor Mineralization, and organized a Morss Colloquium on Precious Metals from Deep-Sea Vents. The Colloquium featured keynote speakers with specialties in marine geology, mineral economics, and international law, and the Secretary-General of the International Seabed Authority, followed by a panel discussion with representatives of industry, the World Wildlife Fund, and the Census of Marine Life program. It was preceded by a two-day science and policy workshop titled "Deep-Sea Mining of Seafloor Massive Sulfides: A Reality for Science and Society in the 21st Century," sponsored by the ChEss project of the Census of Marine Life, InterRidge, U.S. NSF-Ridge 2000, and WHOI's Deep Ocean Exploration Institute. Background information, a list of the 98 participants from more than 20 nations, and links to media about the workshop and colloquium are listed at www.whoi.edu/workshops/deepseamining.

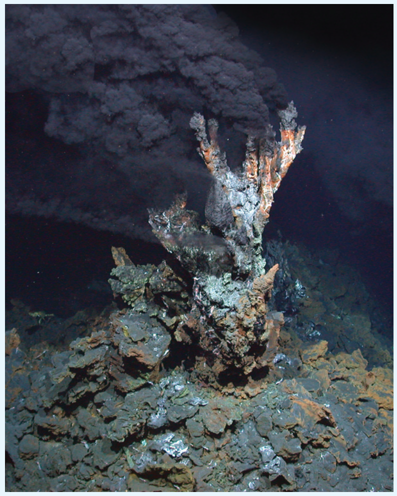


Photo courtesy MARUM, University of Bremen, Germany

Candelabra Vent, Logatchev Hydrothermal Field, Mid-Atlantic Ridge image used for Morss Colloquium event.

The Ocean Ridge Initiative

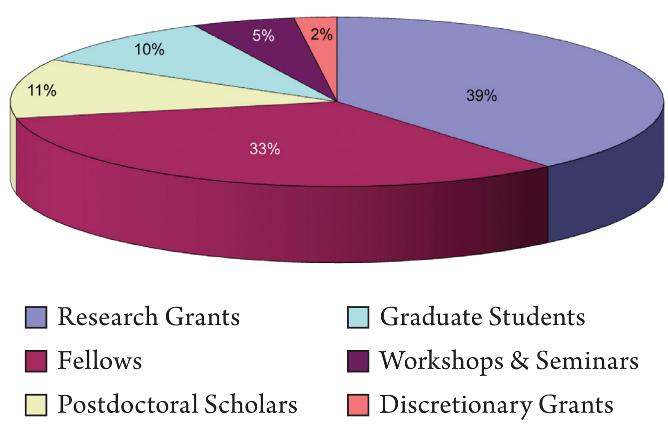
In February 2009, a cross-department workshop was held at WHOI focused on the new Ocean Ridge Initiative (ORI), a program to explore the largest continuous geologic feature on Earth—the mid-ocean ridge system. A total of thirty-six scientists and engineers from all of the five WHOI departments, as well as eight participants from communications and development, came together to discuss needed technological advances for efficient surveying, sensing, sampling, and information exchange, and a range of specific projects to be carried out beneath, along and above the ridges. The aim of the ORI is to make exciting discoveries in the deep ocean through cross-disciplinary collaborations using advanced technologies.

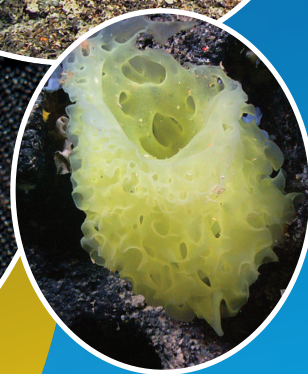
—Meg Tivey

Financial update

The total budget for DOEI from January 2008 to June 2009 was $1,235,598. DOEI allocated the majority of its funds over this time period to research grants (39%) and Fellowships (33%), supporting about 30 WHOI scientists. Funds were provided for WHOI Postdoctoral Scholars (11%) and Joint Program PhD students (10%), fostering development of the next generation of scientists. Funds were also provided for Seminars and Workshops, including the annual Geodynamics Seminar Program (5%). Discretionary funding (2%) was used to support travel, and to facilitate communication and outreach activities by several WHOI scientists and staff. In addition to these budget components, a new Ocean Ridge Initiative, administered by DOEI, was established in early 2009.

DOEI Spending Jan. 2008- June 2009: $1,235,598





About the Deep Ocean Exploration Institute

The Deep Ocean Exploration Institute (DOEI) pursues discoveries that provide a fuller understanding of the planet we live on and offer substantial benefits to humankind. The world's oceans and Earth's crust and mantle beneath them offer some of the best windows into the processes that drive chemical, biological and geological activity, which sustain and shape our dynamic world. DOEI serves the critical role of fostering scientific inquiry throughout Woods Hole Oceanographic Institution, helping to facilitate cross-disciplinary science and engineering advances that enable new discoveries.

Deep Ocean Exploration Institute

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Front cover: Components of the global sulfur cycle (see details on page 4, illustration by E. Paul Oberlander). Back cover: Clockwise from top right, a plexaurid purple coral, a yellow sponge Farrea, and a red anthomastus coral, and at center, a newly-discovered association between Cirrate ("dumbo") octopods who use specific seamount corals to attach their developing eggs. Newborn observed here for the first time. (Tim Shank; DASS 2005 Expedition; IFE, NOAA OE)