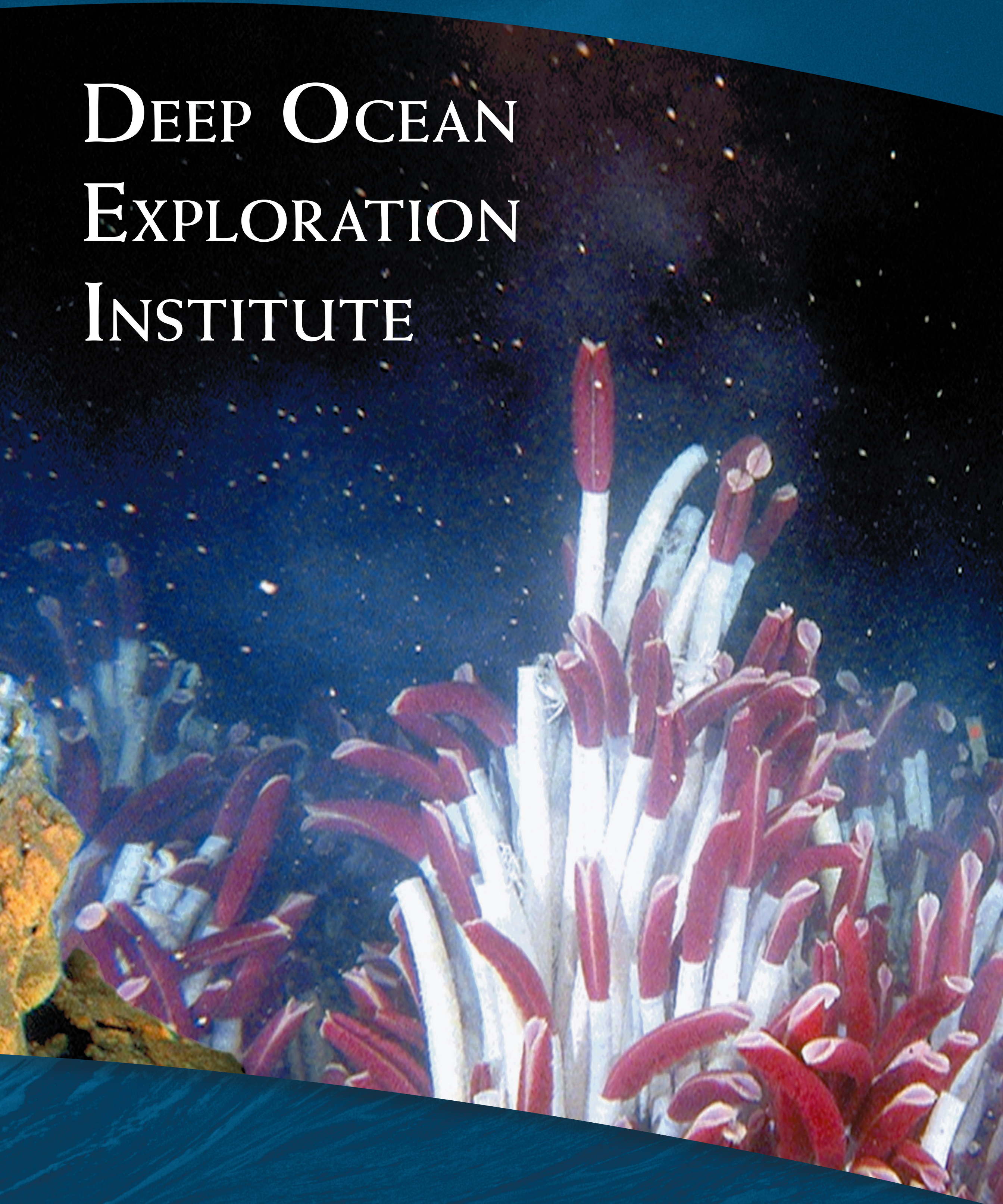
Deep Ocean Exploration Institute



Woods Hole Oceanographic Institution 1930

2010 Report

Woods Hole Oceanographic Institution

Director's Message

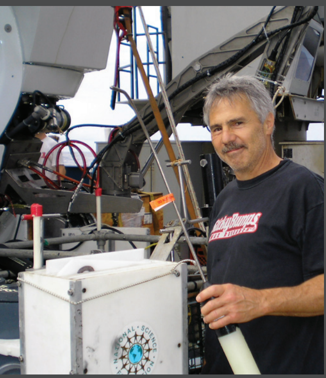


Photo courtesy of Dan Fornari, WHOI

The history of our planet is best revealed by studying the global ocean seafloor. Understanding the geological, chemical and biological processes that form and alter the ocean crust, all of which influence the chemical composition of the ocean, are crucial goals of 21st century oceanographic science. The technological and scientific challenges involved in unraveling these processes and their linkages in space and time are significant. The Deep Ocean Exploration Institute (DOEI) at WHOI plays a key role in supporting scientists, engineers and students working on these topics, fostering innovative cross-disciplinary research and developing unique technologies to explore, map and sample in the deep ocean and beneath the seafloor in Earth's crust and mantle.

In 2010, DOEI continued to support WHOI staff and students through Institute thematic areas and the Ocean Ridge Initiative (ORI), which encompasses a broad agenda of research focused on Earth's most continuous volcanic and tectonic lineament—the global mid-ocean ridge, the 50,000 mile-long undersea mountain chain where oceanic crust is generated.

Initially the ORI has funded research on microbial and dynamic geological/geochemical processes and the nature of deep-sea fauna at oceanic spreading centers. Technology and instrument development that facilitates such studies are an integral part of the ORI.

DOEI's research themes expand the breadth of the ORI by providing opportunities for high-risk/high-reward science that can lead to breakthroughs in our understanding of coupled dynamic processes in deep seafloor environments, from trenches to mid-ocean ridges to continental slopes. DOEI funding has focused on detailed geochemical studies pertaining to the role of the deep earth and ocean in global elemental cycles—especially the role of volatile elements in magmatic and volcanic systems, carbon sequestration in ocean floor strata and investigating what is perhaps the largest unknown ecosystem on this planet, the deep biosphere within the oceanic crust and the deep ocean.

—Dan Fornari

Diving Deep in the Coral Triangle

MIT-WHOI Joint Program student Santiago Herrera grew up in the Andes Mountains, but his thoughts always turned to the sea.

"The ocean was always a fascinating and enigmatic place for me," Herrera said. "It was clear to me that I wanted to learn more about the ocean environment and the organisms living in it."

Today he is doing just that. Working alongside Associate Scientist and DOEI Fellow Tim Shank in the Biology Department, Herrera is analyzing recent video from the Coral Triangle—a region in the South Pacific where more than 65 percent of the world's shallow-water reef-forming coral species live—to prepare for future studies of this abundant ecosystem and others.

"The most exciting aspect of working in the deep Coral Triangle is the fact that this region is well known as the biodiversity epicenter for shallow-water marine fauna, but until last summer's expedition, nobody had been able to observe and document *in situ* the biodiversity found in deep waters," he explained. "From the observations we made, it seems very likely that this region also constitutes a biodiversity hot-spot in the deep sea."

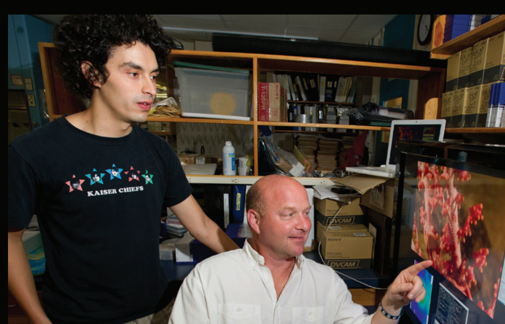
In summer 2010, Shank participated as a "virtual" chief scientist, with an international team led by U.S. and Indonesian researchers, on cruises exploring deep Indonesian waters in the Coral Triangle. He collected high-definition video imagery during dives by the *Little Hercules* ROV from the NOAA ship *Okeanos Explorer*. Researchers discovered a diverse abundance of deep corals that they believe may be the highest in the world, and imaged 40 potentially new deep-sea species.

"This expedition provides baseline data to let us better understand these ecosystems and identify future changes, information important in Indonesian seas and around the world," DOEI Director Dan Fornari said.

The team made presentations about this project at the American Geophysical Union annual meeting in late 2010. Their paper, "Biodiversity of the Deep-Sea Benthic Fauna in the Sangihe-Talaud Region, Indonesia: Observations from the INDEX-SATAL 2010 Expedition," was named an outstanding student paper.

Further sampling is the next logical step for the study of life in the Coral Triangle, Herrera added. "This would allow us to test specific hypotheses regarding the diversity and evolution of the organisms found in this area. It also would be tremendously interesting to be able to explore other areas, such as the Halmahera Sea within the Coral Triangle."

DOEI awarded Tim Shank and Santiago Herrera of the Biology Department $57,972 for the "First Investigation of Recently Discovered Cold-Water Coral Ecosystems in the Deep Coral Triangle."



Tom Kleindinst, WHOI

Santiago Herrera and Tim Shank (above) examine images from the Coral Triangle. Among the extraordinary biodiversity found at seamount K (below) are several varieties of corals and a hermit crab (top left), which utilizes the three-dimensional habitat provided by the red soft coral.

Images courtesy of NOAA Okeanos Explorer Program, INDEX-SATAL 2010

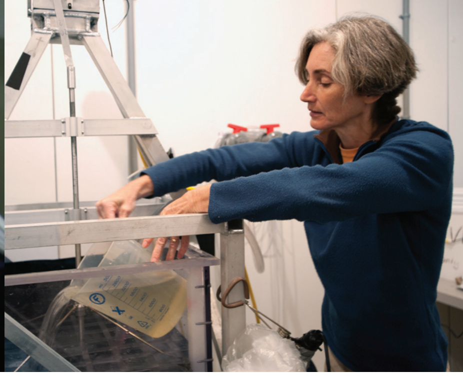
Resilience in the Depths

ORI funds a rare look at how hydrothermal vent communities overcome disaster

Working in a rare, “natural seafloor laboratory” of hydrothermal vents in the East Pacific Rise (EPR) that had just been rocked by a volcanic eruption, Senior Scientist Lauren Mullineaux and her team discovered last year what they believe is an undersea superhighway carrying tiny life forms unprecedented distances to inhabit post-eruption sites. The research offers a surprising new look at how large currents on the ocean surface may influence deep-sea currents.

The discovery—in collaboration with the Lamont-Doherty Earth Observatory and the NOAA Pacific Marine Environmental Laboratory—clashed with the widely accepted assumption that when local adult fauna is wiped out in a hydrothermal eruption, it is replaced by a pool of tiny creatures from nearby vents. In this case, however, the larvae that resettled the post-eruption vent area are noticeably different from the species that were destroyed and appeared to have traveled great distances to do so, some as far as 300 kilometers. The study was published in the journal *Science*, with Joint Program alumna Diane Adams as the first author.

Top photos: Left and center courtesy of Susan Mills, WHOI; right Jayne M. Iafrate, WHOI; Illustrations: E. Paul Oberlander, WHOI



The post-eruption limpet Ctenopelta *(above left) was an unexpected find. Settlement surfaces (center), which capture fauna samples, recovered after 2 1/2 years show a vent mussel and several limpets. Lauren Mullineaux's Shore Lab facility in Woods Hole allows her to study larval transport.*

Today, with funding from the Deep Ocean Exploration Institute, Mullineaux and Research Associate Susan Mills are returning to the EPR, studying the long-term colonization dynamics of these vent communities in order to answer several important questions:

- ***Will these pioneer species persist and lead to a stable new community?***
- ***Will the colony transition back to pre-eruption fauna?***
- ***What is the role of these pioneers in subsequent environmental changes in the recovery of EPR vent communities?***

"If these new pioneers persist and cause a regime shift, that will expand their range and increase the regional diversity," Mullineaux explained, saying that the findings have implications for the wider distribution of undersea life.

The discovery by WHOI researchers of hydrothermal vents on the bottom of the Pacific Ocean in 1977 revolutionized ideas about where and how life could exist. The vents teem with life, supported by the hot chemicals that spew from the vents and provide food through microbial chemosynthesis, a deep-sea version of photosynthesis.

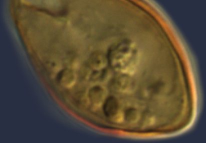
Mullineaux's group had been studying a vent community on the EPR for 15 years when, in 2006, a seafloor eruption was detected at the site. The eruption wiped out the once thriving fauna, and provided Mullineaux a unique opportunity to study how fauna rebound from such catastrophic events. What she and her group found, however, was unexpected: *Ctenopelta porifera*, a gastropod that likely emigrated from another vent site more than 300 kilometers away.

"This was a striking change," Mills said. "The arrival of *Ctenopelta porifera*, and the disappearance of other organisms, gives us a unique opportunity to understand how chemical and biological changes in a vent community impact the larval supply."

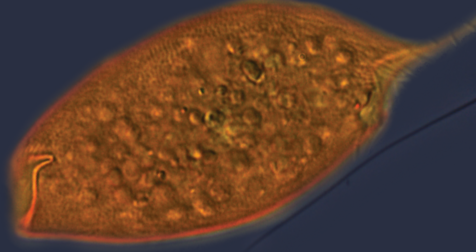
This research also may open up new ways of looking at the impacts of human activities on the seafloor, such as seafloor mineral mining, which could alter a vent site in a similar way to an eruption. Depending on the site, such activity could conceivably foster a greater diversity of species at a vent that has just been mined, or it could cause extinction, Mullineaux said.

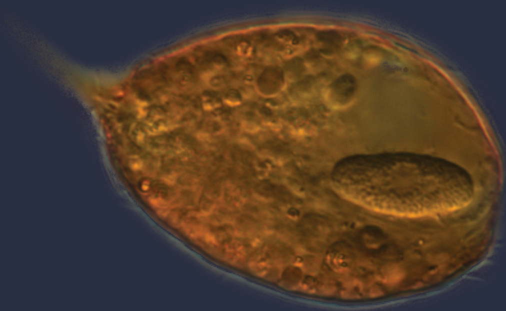
"Plots of the seafloor are targeted for deep mining," she said. "We need to know how resilient such colonies are before the sites are mined, and that will gives us clues to possible human impacts. We have ideas about resilience, and this site and this funding gives us a chance to test those ideas."

The Deep Ocean Exploration Institute's Ocean Ridge Initiative granted $26,438 to Lauren Mullineaux and Susan Mills for the proposal "Collaborative Studies of Post-eruption Colonization Dynamics on EPR Vents."



A Place at the Table for Protists





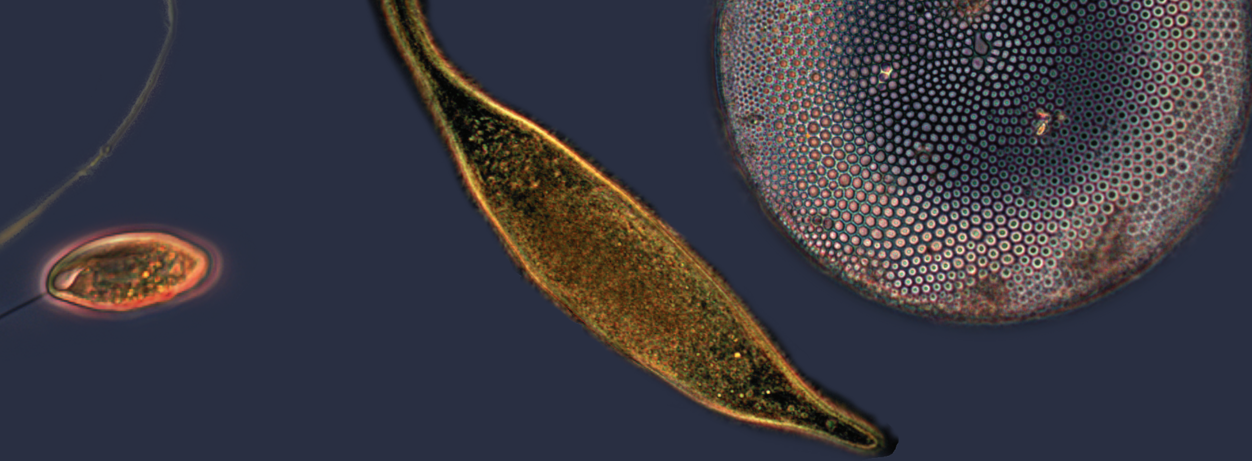
Some of the ocean's smallest organisms may play a big role in degrading marine hydrocarbons

The Deepwater Horizon oil spill in the Gulf of Mexico has highlighted the need to better understand the long-term consequences of petroleum contamination in the ocean. One of the many lingering questions concerns how hydrocarbons are degraded in deep-sea sediment, and the impact of biodegradation on the ocean food web. Research Specialist Virginia Edgcomb of the Geology and Geophysics Department believes that some of the ocean's smallest eukaryotic organisms, i.e., ones with specialized organelles and a nucleus, may play a large role in answering that question.

Edgcomb and her peers know that many of the protists—the unicellular microorganisms that are an essential component of microbial food webs—graze on bacteria (and other protists) and are preyed upon by zooplankton, filter feeders and fishes. Selective grazing by protists can also alter the structure of bacterial communities and effectively eliminate some types while enabling others to flourish. They play key roles in global biogeochemical cycles either directly or through their grazing, and in the transportation of hydrocarbons to higher levels of the web. While many researchers are focusing on how bacteria degrade hydrocarbons, few are turning their sights to the role of protists.

"We want to know whether deep-sea protists enhance the degradation of hydrocarbons by the bacteria, and whether their presence leads to a restructuring of the *in situ* bacterial communities," Edgcomb explained. "By studying the effect of *in situ* deep-sea protist populations on the degradation of hydrocarbons, including under anaerobic conditions, this DOEI project will allow us to better model the long-term consequences of oil contamination on deep sediments and their biological communties."

To test her idea, Edgcomb obtained "four large bottles of muck"—black mud from a Gulf hydrocarbon seep southwest of the Mississippi Delta—and divided it among a series of test tubes that would be spiked with fossil diesel oil. Hydrocarbon degradation is typically limited by the bioavailability of nutrients such as nitrogen and phosphorous, so those were added to certain samples to examine hydrocarbon degradation under more nutrient-rich conditions. Some samples were treated with protist inhibitors to compare the degradation of these hydrocarbons in the



presence and absence of protists. Some samples were incubated under aerobic and some under anaerobic conditions. And then she waited.

"Protists and bacteria eat what they like to eat, and some bacteria are attracted to certain components of complex hydrocarbons," Edgcomb said. "Under certain conditions bacteria for example will metabolize some hydrocarbons very rapidly. Aerobic conditions tend to speed the process of biodegradation. If selective grazing of the bacterial community by the protists is occurring, this can enhance or diminish biomineralization of hydrocarbons in the sediments depending on whether or not grazing targets members of the community that are active in this biomineralization process."

During the summer Edgcomb, together with David Beaudoin and Catherine Carmichael, a research assistant in Senior Scientist Christopher Reddy's lab, examined the samples using gas chromatography to detect changes in the composition and abundance of hydrocarbons in the tubes over the time course of the experiment.

Edgcomb will also extract ribonucleic acid (RNA) and amplify the small subunit ribosomal RNA gene from each sample to "see who's there." These molecular methods will help Edgcomb and other researchers monitor changes in protist and bacteria communities in the different samples and look for correlations with changes in hydrocarbon composition in the experimental tubes.

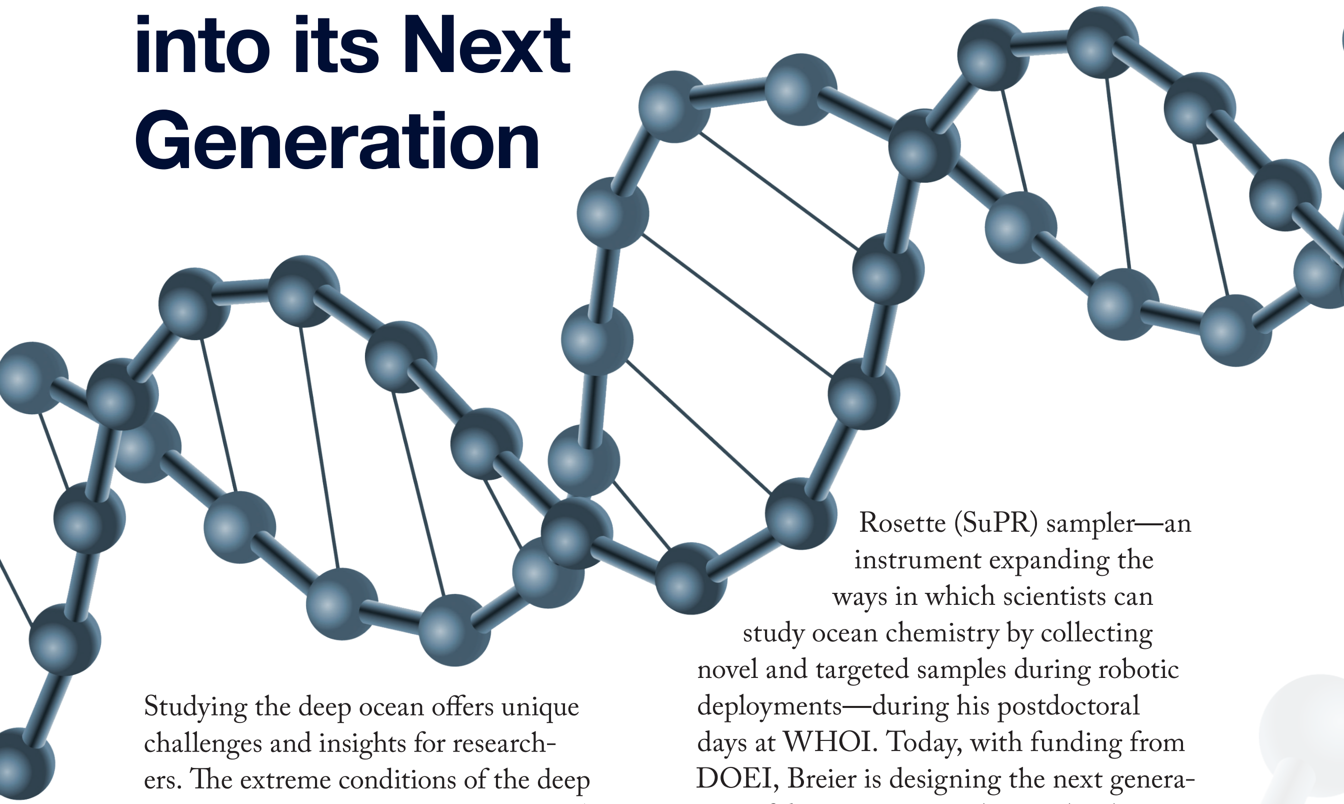
While there are certain caveats involved in extrapolating lab results to real-world conditions, Edgcomb believes her results will provide the initial data to justify a full proposal to the National Science Foundation for an expanded study of the response of protist communities to hydrocarbon exposure and the role of protists in hydrocarbon degradation in the Gulf.

DOEI and the Ocean Ridge Initiative granted $67,298 for Edgcomb's study, "Protist Stimulation of Biodegradation of Hydrocarbons by in situ *Deep Sea Bacterial Communities."*

Tom Kleindinst, WHOI; Protist photos by Virginia Edgcomb, WHOI

WHOI biologist Virginia Edgcomb is testing whether bacteria consume more petroleum compounds when they are subject to predation than when they are undisturbed. The predators in this case are microscopic, mostly single-celled organisms called protists (top of page).

New Technology Advances Ocean Science into its Next Generation



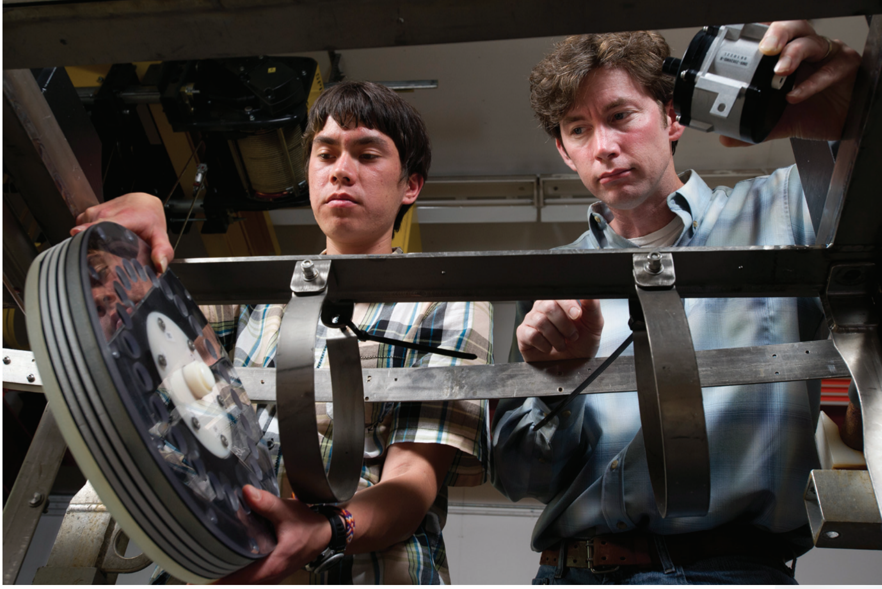
Studying the deep ocean offers unique challenges and insights for researchers. The extreme conditions of the deep sea are unlike any on Earth's surface. At hydrothermal vents, for example, pressures are crushing, temperatures range from of 400°C to near freezing in the space of centimeters, and the water chemistry is corrosive and toxic. For many specially adapted organisms, however, that water is life-giving.

To really understand the cycle of life in the deep sea, researchers need samples to measure chemistry and DNA. And they aren't after just any samples; the ones with the most to offer are likely to come from the extremes, such as a submarine volcanic eruption. Getting samples like those means figuring out how to get your equipment to the right place at the right time, and preserving and protecting the samples until you can get them back.

To Assistant Scientist Chip Breier, these challenges are more exciting than daunting. A former U.S. Navy officer who designed pumps for nuclear submarine reactors, Breier developed the Suspended Particulate Rosette (SuPR) sampler—an instrument expanding the ways in which scientists can study ocean chemistry by collecting novel and targeted samples during robotic deployments—during his postdoctoral days at WHOI. Today, with funding from DOEI, Breier is designing the next generation of deep-ocean sampling technology.

Breier's new tool, designed to be attached to an autonomous underwater vehicle (AUV), will enable collection of suspended particulate matter, micro-organisms and water samples during multi-depth, robotic surveys. It will allow scientists to use AUVs to find and sample geochemical and microbial "hotspots" in response to tectonic and volcanic events, which can induce major changes in deep sea chemistry and potentially provide a major pulse of energy to a variety of micro-organisms.

By operating in a sensor-driven "smart-sampling" mode, an AUV so equipped will be able to locate and collect the optimum samples for mapping out the distribution of these geochemical plumes and the microbial response. This ability is a critical step toward using pre-deployed AUVs, which might wait on-site for months to years, to conduct autonomous scientific missions in response to events originating on and



Tom Kleindinst, WHOI

Summer Student Fellow Kevin Mori and Asisstant Scientist Chip Breier fit sampling instruments on the Sentry *frame.*

beneath the ocean floor. The intent is to enable novel ways of addressing scientific questions concerning the global exchange of material between the seafloor and the oceans, and the temporal relationship between that exchange and tectonic and volcanic cycles on a mid-ocean ridge axis.

"Life in the deep sea is on a different schedule and, around mid-ocean ridges, the schedule is set by catastrophes. To witness them and their consequences, you have to plan ahead," Breier said. "These samples will help us tell the untold story about the cycle of life in the deep sea."

To develop a robust sampler that can deploy on an AUV like *Sentry* is no small feat. Besides having to design a lightweight, low-power instrument that can survive extreme pressures and preserve samples as well as collect them, Breier also has to consider an equally important issue: size.

"*Sentry* is like a sports car, and the sampler has to fit under the hood," Breier explained. "We have to figure out how to shrink the size of our sampling tools, and at the same time make them more capable."

In order to create the right instrument, Breier and his team don't just design and build one version. On the computer they can virtually "build" a number of competing designs; the top designs move on to prototyping and testing until a finalist emerges. This sort of internal competition offers the scientists and engineers involved unique opportunities to challenge themselves and each other to develop an instrument that is best suited for the many applications and missions it will conduct.

Breier expects one of the sampler's first missions will be within an ocean observing infrastructure such as the Endurance Array currently being deployed on the Juan de Fuca Plate off the coasts of Oregon and Washington. The Endurance Array is a long-term observatory of moored and mobile assets deployed across the continental shelf and slope. WHOI is playing a lead role in the development of this array and several others around the world, an effort that will significantly move ocean science into its next generation by focusing on continuous observations at key locations, documenting episodic events and longer-term changes.

"At WHOI, I get to combine my science, engineering, and fascination with the ocean; it's fantastic," Breier added. "Uncovering the mechanisms driving ocean and Earth processes, especially hidden processes that we haven't been able to study previously—that's exciting."

DOEI awarded Chip Brier $73,263 to develop the next generation in water column sampling technology.

2010 DOEI Funded Projects

John "Chip" Breier of the Applied Ocean Physics and Engineering Department was awarded $73,263 for the proposal "Developing a Compact, Reconfigurable, Discrete Sample Collection (DiSC) system for Water-Column Biogeochemical Studies using Autonomous Underwater Vehicles." See page 8-9 for more about his project.

Virginia Edgcomb of the Geology and Geophysics Department was awarded $67,298 for the proposal "Protist Stimulation of Biodegradation of Hydrocarbons by *in situ* Deep Sea Bacterial Communities." See pages 6-7 for a more about her work.

DOEI and the Access to the Sea Fund teamed to award $69,756 to **James Kinsey** of the Applied Ocean Physics and Engineering Department for the development and field deployment of a novel autonomous underwater vehicle (AUV) gravimeter. Gravity measurements can provide valuable information about the density and porosity of the sub-seafloor structure, and provide crucial additional constraints on the shallow oceanic crustal structure. Presently, there is no gravimeter suitable for use on an AUV, and Kinsey believes this new sensing capability will augment and enhance the instrumentation already on the *Sentry* AUV and motivate new investigations in using gravimetry to improve our understanding of the shallow oceanic crust.

DOEI Fellow Tim Shank and **Santiago Herrera** of the Biology Department were awarded $57,972 for the proposal "First Investigation of Recently Discovered Cold-Water Coral Ecosystems in the Deep Coral Triangle." See pages 2-3 for more about their work.

Nobu Shimizu and **Horst Marschall** of the Geology and Geophysics were awarded $74,141 to study "Sulfur Isotopes in Subduction Systems and the Global Sulfur Cycle." Sulfur is one of the six most abundant elements in the Earth with four stable isotopes. Despite the unique geochemical importance of sulfur, surprisingly little is known on the behavior of sulfur and sulfur isotopes during high-pressure metamorphism (HPM) and subduction zone devolatilization. Shimizu and Marschall aim to close this gap, and investigate the S isotope composition of sulfides and sulfate components in natural high-pressure rock samples. Studies of sulfur isotopes on non-volcanic subduction-related material are very rare, and no data on any HPM rocks have been published to date.

Ocean Ridge Initiative projects funded in 2010

Henry Dick and **Frieder Klein** of the Geology and Geophysics Department received $8,564 to conduct a systematic study of carbonate-altered serpentinite minerals—minerals that take up carbon dioxide—from several types of hydrothermal vent systems. They are analyzing the composition and associations of secondary minerals in these rocks using classic and new methods to unravel reaction pathways during CO_2 uptake. Their results will provide valuable new insights into the process of carbonate alteration in serpentinites and the consequences for CO_2 exchange between the abyssal mantle and the ocean.

Susan Humphris of the Geology and Geophysics Department and MIT/WHOI Joint Program student **Evelyn Mervine** received $35,463 to determine the natural rate of carbonation of mantle rocks (or peridotite) in an ophiolite—a section of oceanic crust and mantle exposed to the atmosphere by tectonic uplifting. Considerable attention has focused on carbon capture and storage as a way to mitigate CO_2 input to the atmosphere from human activities. One proposed option is to increase the conversion of CO_2 gas to stable, solid carbonate minerals, which happens when mantle rock is exposed to the atmosphere. Susan and Evy are studying the Samail Ophiolite in Oman—one of the world's largest and best-exposed ophiolites—and measuring the volume, ages and weathering rates in ophiolite layers, which will let them quantify the residence time of carbon in three kinds of carbonate-altered rocks within the ophiolite, some of them 350,000 years old.

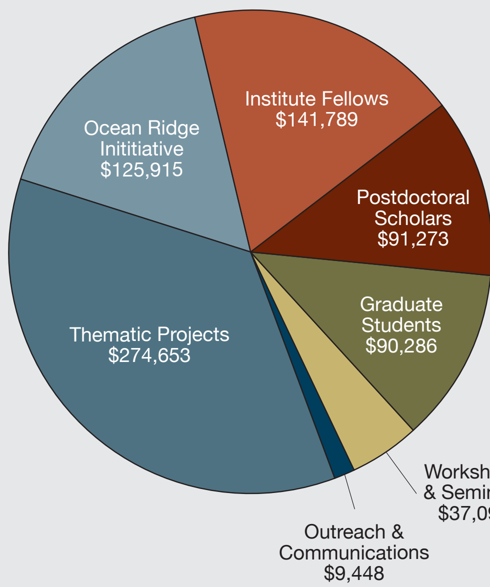
Lauren Mullineaux and **Susan Mills** of the Biology Department were awarded $26,438 to study how submarine eruptions along a mid-ocean ridge, the East Pacific Rise (EPR), affect the supply of larvae and the recolonization of fauna specific to hydrothermal vents. See pages 4-5 for more about their project.

Jared Goldstone, **Tim Shank** and **John Stegeman** of the Biology Department were awarded $21,801 to identify genetic (DNA) sequences that can be used as markers of organic chemical (hydrocarbon) exposure in deep-sea mussels, *Bathymodiolus thermophilus* and related species. When exposed to such toxins, animals employ (express) specific genes to produce the enzymes that detoxify those compounds, but how animals in vent or seep environments accomplish this task is not known. It's hard to obtain samples for genetic analysis from the deep sea, so little information is available on the mussels' gene sequences or genes expressed. But they are closely related to a shallow-water species, the blue mussel, for which researchers do have gene sequences. By analyzing evolutionary relationships between mussel species, the team will identify *Bathymodiolus* gene sequences expressed when the mussels are exposed to organic chemicals, which in turn will help define the chemical environment that animals experience at deep-sea vents and hydrocarbon seeps.

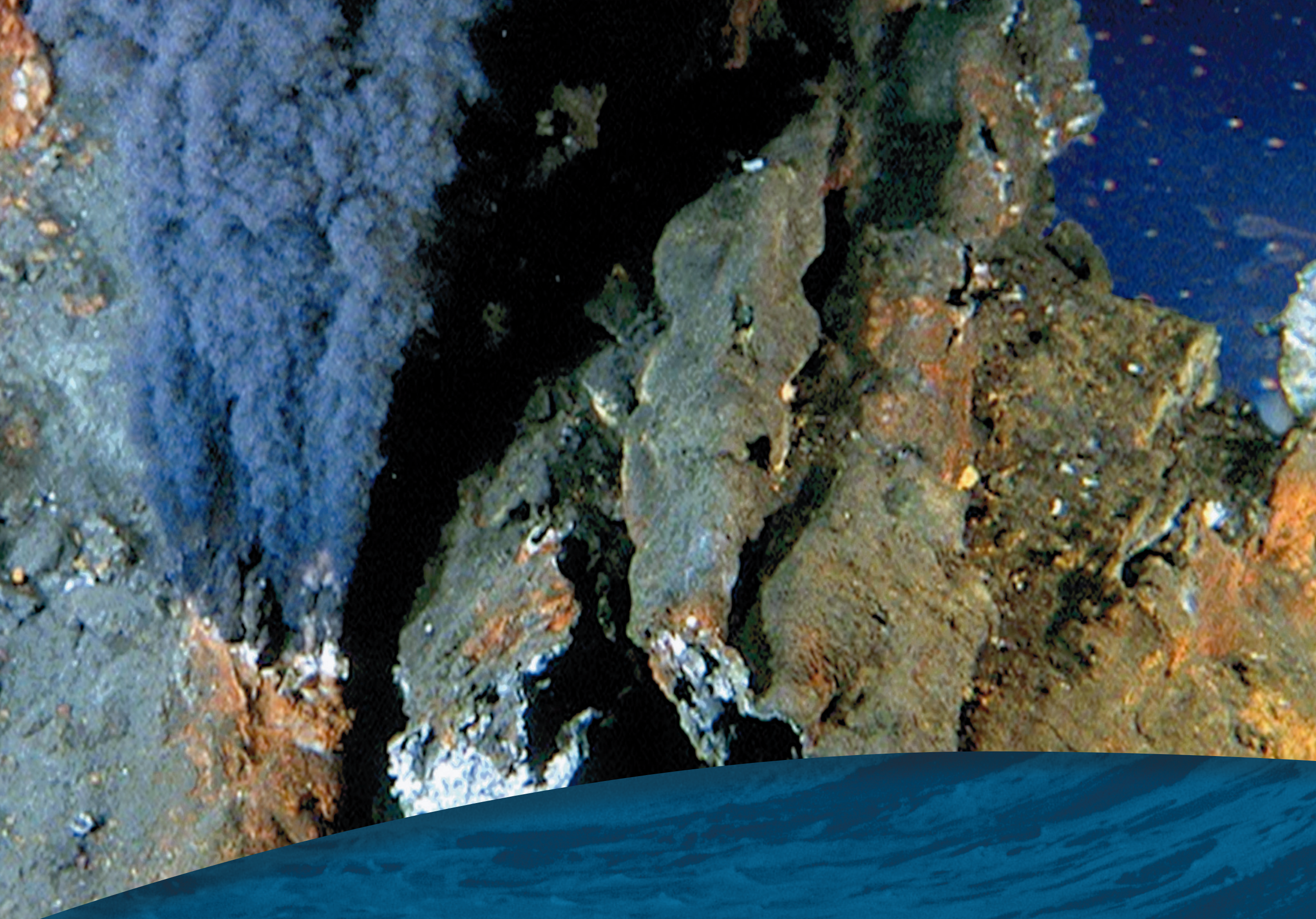
Funding highlights

Although DOEI focused the majority of its funding on research grants, significant support also went to fellows, graduate education and outreach activities. In 2010, DOEI supported two Institute Fellows (Mark Behn and Jeff McGuire), postdoctoral scholars Dorsey Wanless, Frieder Klein and Tetsuo Matsuno, and MIT/WHOI Joint Program student Emily Roland. Funds also provided support for educational activities, such as the annual Geodynamics Program. Discretionary and Communication funding was used to support conferences and publications.

2010 DOEI Spending: $770,460



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.



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Front cover: The seafloor is a window into the underlying forces that forge and shape the face of our planet. Photo composite made from IMAX film by William Reeve and Stephen Low, Stephen Low Productions.

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