



DEEP OCEAN EXPLORATION INSTITUTE



SUMMER 2008 REPORT

Woods Hole Oceanographic Institution

Message from the DOEI Director

The processes that control how our planet works are intimately tied to the global ocean—the one unique characteristic of Earth in our Solar system and perhaps beyond. The goal of the Deep Ocean Exploration Institute (DOEI) is to investigate the inter-related geological, chemical and biological processes that occur within the deep ocean and Earth's interior, and to stimulate cutting-edge research in the earth, ocean and technological sciences.

The past century has brought revolutionary advances in our broad understanding of the planet, but detailed knowledge of the interactions between earth-forming and life-forming processes is just now becoming apparent. We have been slowed by the inaccessibility of remote parts of the planet, especially the deep ocean and subsurface within Earth's crust, and the challenges related to measuring Earth's dynamics over very long and very short scales of time and space. But this is changing.

DOEI promotes high-risk, high-reward exploration of remote parts of the planet with innovative technologies and interdisciplinary investigations. DOEI-funded researchers are particularly interested in understanding the flow of both magma and water within the planet; the nature and evolution of biological communities in the deep ocean and Earth's crust; and the characteristics of planetary processes that shape Earth. We also support engineers and scientists in the development of undersea technologies and the establishment of seafloor observatories in various settings.

DOEI has played an important role in WHOI's educational and outreach efforts by sponsoring the Geodynamics Seminar Series. In 2007, the seminar topic was "Dynamics of Continental Margins." In addition, DOEI supports graduate students and postdoctoral fellows in various departments, and fosters K-12 and public outreach via Dive and Discover™ web expeditions.

In 2007, we selected two DOEI Fellows who represent the broad spectrum of research within DOEI's portfolio—Tim Shank in Biology and Maurice Tivey in Geology

& Geophysics. Each is doing cutting-edge work that promises to open up new fields of research and funding opportunities. Maurice describes some of the impacts that his near-bottom geophysical work have on the newly developing industry of seafloor mineral exploration and extraction. By bringing scientists and industry together, he is working to promote responsible assessment of the potential environmental issues related to mining at seafloor hydrothermal vents.

Jeff McGuire and John Collins are a dynamic team—representing one of the most talented geophysical groups worldwide both in terms of instrument development and cutting edge seismic theory. Their DOEI-sponsored research promises to revolutionize how we implement effective earthquake warning systems off the US west coast and elsewhere worldwide where this threat exists. Their work has important societal and economic implications, as well as being at the forefront of ocean bottom seismological instrument development and earthquake theory.

Chip Breier's unique background in both ocean chemistry and engineering enables him to work simultaneously with Chris German in Geology & Geophysics and Sheri White in Applied Ocean Physics & Engineering. Using an elegant technical approach, Chip is tackling important scientific questions about the nature of hydrothermal plume particles to determine how their chemistry may be affecting microbial processes at deep-sea vents.

I hope that you enjoy learning about recent work sponsored by DOEI and invite you to also visit our Web site (www.whoi.edu/institutes/doi), which has more detailed information on all of the funded projects and related information since DOEI's inception in 2001. Supporting DOEI means supporting the future of WHOI's excellent team of scientists and staff, who are working to solve the mysteries of our dynamic Earth and its global ocean.

—Dan Fornari

Seafloor Mining

A renewed interest in research on Earth's magnetic field



Since the discovery of deep-sea hydrothermal vents in 1977 and high-temperature “black smoker” vents in 1979, scientists have realized that these sites are important sources of ore formation. Recently, there has

been a resurgence of interest in marine mining. A number of small commercial marine mining companies have emerged specifically to harvest seafloor metallic deposits that comprise the mineralized core of hydrothermal vent systems. This resurgence in marine mining has been encouraged by a number of factors: the recent rapid rise in metal prices, the maturing of offshore deep-sea technology, and the willingness of countries with offshore resources to make their marine territories available for exploration and exploitation.

As part of my DOEI Fellowship, I am investigating how WHOI and the science community can both benefit from these developments and also determine what role science can play in encouraging responsible resource extraction. A number of challenging issues are connected to the exploitation of seafloor mineral deposits. Information and education on hydrothermal vent systems are needed by various groups: the mining companies exploring and developing new prospects, governments with seafloor resources on hand for exploration, the International Seabed Authority (the United Nations body that oversees blue water resources), and non-governmental organizations (NGOs) evaluating the environmental impact of such development.

I have made a number of industrial contacts and have established a Working Group in Seafloor Mineralization under the auspices of InterRidge (<http://www.interridge.org>), an international organization devoted to studying oceanic ridge systems. Along with InterRidge and the global network of scientists involved with the Census for Marine Life (<http://www.coml.org>), I have organized a workshop and policy forum to be held in 2009 to bring together science, industry, policy makers, and

environmental organizations to discuss how such resources can be responsibly shared, developed, and, in some cases, protected.

My own research, which has garnered the attention of the seafloor mining industry, examines Earth's magnetic field to understand marine geologic processes. For example, some of my studies have investigated very young ocean crust formed at mid-ocean ridges during the past few thousand years. I have developed techniques to obtain high-resolution magnetic measurements in the deep sea using towed instrument systems, human occupied submersibles, remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs).

My research at mid-ocean ridges has examined the effects of hydrothermal vent processes on crustal magnetization. I have found a dramatic link between discrete zones of demagnetized crust and the areas that feed seafloor vent systems, called up-flow zones. This link helps indicate the patterns of subsurface hydrothermal fluid circulation and mineral deposition. This has been helpful, because the detailed subsurface structure of hydrothermal vents on a scale of tens of meters has been difficult to address with most geophysical techniques. So far, magnetic-field mapping has been the only routine measurement capable of showing this fine-scale structure. Even so, constraints on the depth extent of these up-flow zones and areas of mineralization remain fuzzy, so there is more work to be done.

With my DOEI Fellowship I am exploring new magnetic gradient mapping techniques, and I have begun a project with WHOI engineers James Kinsey and Dana Yoerger. Our goal is to develop a continuously measuring gravity sensor for use on AUVs that should provide independent information on the fine-scale crustal structure of vent systems. The new technique may, in turn, become a useful tool for the seafloor mining industry as well.

—Maurice Tivey

Earthquake Warning

Prototype early warning systems in the sea

Most of the largest earthquakes—those that register at magnitudes of 8 and 9—occur underneath the ocean along the planet’s many subduction zones—sites where lithospheric plates are being pulled down into Earth’s mantle. The stresses that build up as the plates are subducted and the heating that occurs trigger earthquakes and volcanism. Gigantic quakes at these sites take anywhere from one to ten minutes to rupture along 100 miles or more of the fault.

Because these ruptures typically occur offshore underneath the continental slope and shelf, it takes even longer for the seismic waves that cause strong shaking to travel from the fault to the shore, where they damage buildings and other structures. This inherent lead-time between when a rupture begins offshore and when strong shaking starts on land presents an opportunity to warn people of impending danger.

On land, particularly in Japan, where instrumentation is plentiful, Internet communication is instantaneous, and logistics are simplest, seismologists have implemented an Earthquake Early Warning system. The Japanese system detects earthquakes, determines their magnitudes, and issues alerts automatically—without the need for human intervention. Within just a few seconds after a major earthquake has begun, broadcasts are available around the region and critical systems like trains and gas lines can be shut down before the strong shaking begins.

In America, the largest earthquake recorded—a magnitude 9 in 1964—occurred primarily offshore of Alaska. The nearby Cascadia subduction zone, off the coast of Oregon and Washington, has not had a large earthquake since the early 1700s and is now thought to have built up enough strain to generate a truly great rupture. Despite this looming threat, the cities of Seattle and Portland, which have very large urban populations, do not yet possess effective earthquake early warning systems. While both of these regions have extensive networks of seismometers on land, neither has a single telemetered seismometer on the seafloor close to the site

where the next great earthquake will likely begin. This deficiency in ocean-based instrumentation could waste precious tens of seconds of potential warning time.

In contrast, the country of Oman has a real-time earthquake warning system based on a WHOI-built offshore seismic observatory that is connected to shore via a fiber-optic cable. With DOEI funding, we are currently in the process of developing a prototype offshore earthquake early warning system for the U.S. West Coast. The problem is more complex here than in Oman, due to the extremely large area that needs to be monitored—from Northern California to Canada and from the coastline to 100 kilometers offshore. Covering such a large area with a cabled telemetry system is not financially feasible; however, a network of buoy-based systems might be. As a preliminary step, in 2004/2005, WHOI deployed an acoustically-linked, moored-buoy seismic observatory in the water on the Nootka fault, roughly 80 kilometers offshore of Vancouver Island, Canada. The system worked well throughout its 13-month deployment, surviving several periods of extreme weather and sea states.

The primary data source for the Nootka observatory was a WHOI Ocean Bottom Seismometer (OBS), which records seismic movement on the seafloor. OBS data were telemetered acoustically from the OBS to a surface buoy via a WHOI-designed high-speed acoustic modem and then ashore via an Iridium satellite communications system. The combination OBS and acoustically-linked mooring was designed as a system for long-term scientific monitoring of earthquake activity, which worked very efficiently for the task at hand.

To advance the technology and create an earthquake-warning system, we need to make some adjustments. For example, for the long-term scientific monitoring, the data were *pulled* from the buoy on the basis of a pre-determined schedule or a shore-based request. For an earthquake-warning system, the data must be *pushed* from the OBS as soon as it detects movement in a virtually instantaneous manner. Whereas the previous

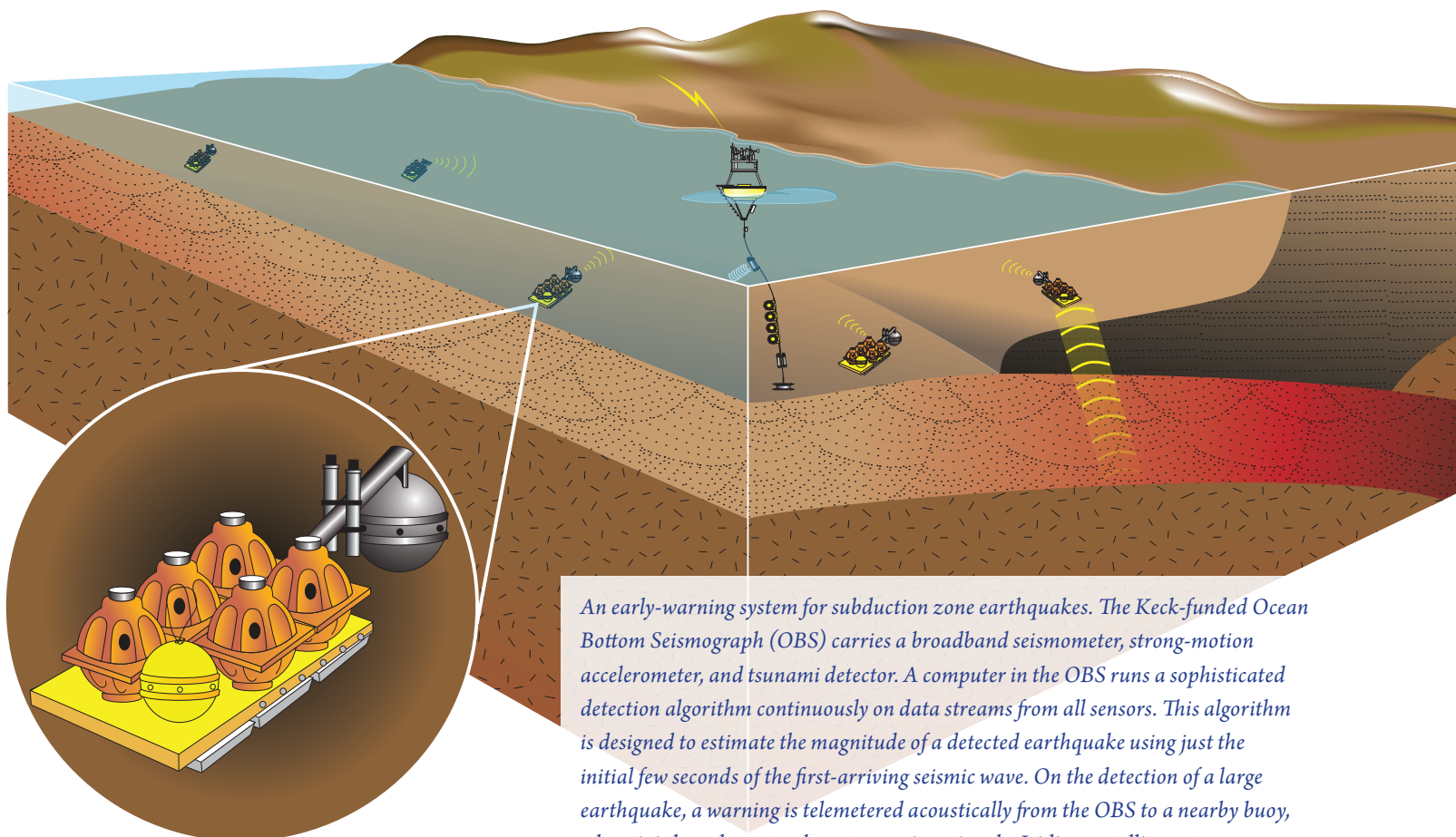
system stored the data for as much as six hours before transmitting, the new system will transmit as soon as motion is detected.

For seismologists, the prediction of the magnitude of a rupture is made possible by mathematical equations called earthquake early warning (EEW) algorithms. These formulas calculate movement from the first few seconds of an earthquake and allow hazard mitigation before the destructive wave arrives on shore. With DOEI funding, our research team, along with Frederik Simons of Princeton University, developed and tested an EEW algorithm using data recorded offshore of Hokkaido, Japan near the epicenter of the 2003 Tokachi-Oki earthquake (magnitude 8.1) and its aftershocks. The algorithm made use of a signal processing technique called a *wavelet transform*, in which waveform amplitude

and frequency data from the first few seconds of motion are concentrated into a single metric. We found that wavelets of four seconds provide the needed information for an EEW that is accurate enough to be used for an effective earthquake early warning system.

We are now in the process of incorporating this new EEW algorithm on a new WHOI OBS. Unlike the system deployed offshore Vancouver Island, we are now obtaining data with a delay of only one second, as opposed to six hours. Once the technique is perfected, we hope to obtain funding for the deployment of a buoy-based prototype observatory off the west coast of Alaska. This will provide the first ocean-based earthquake early warning system in the United States—with more to follow.

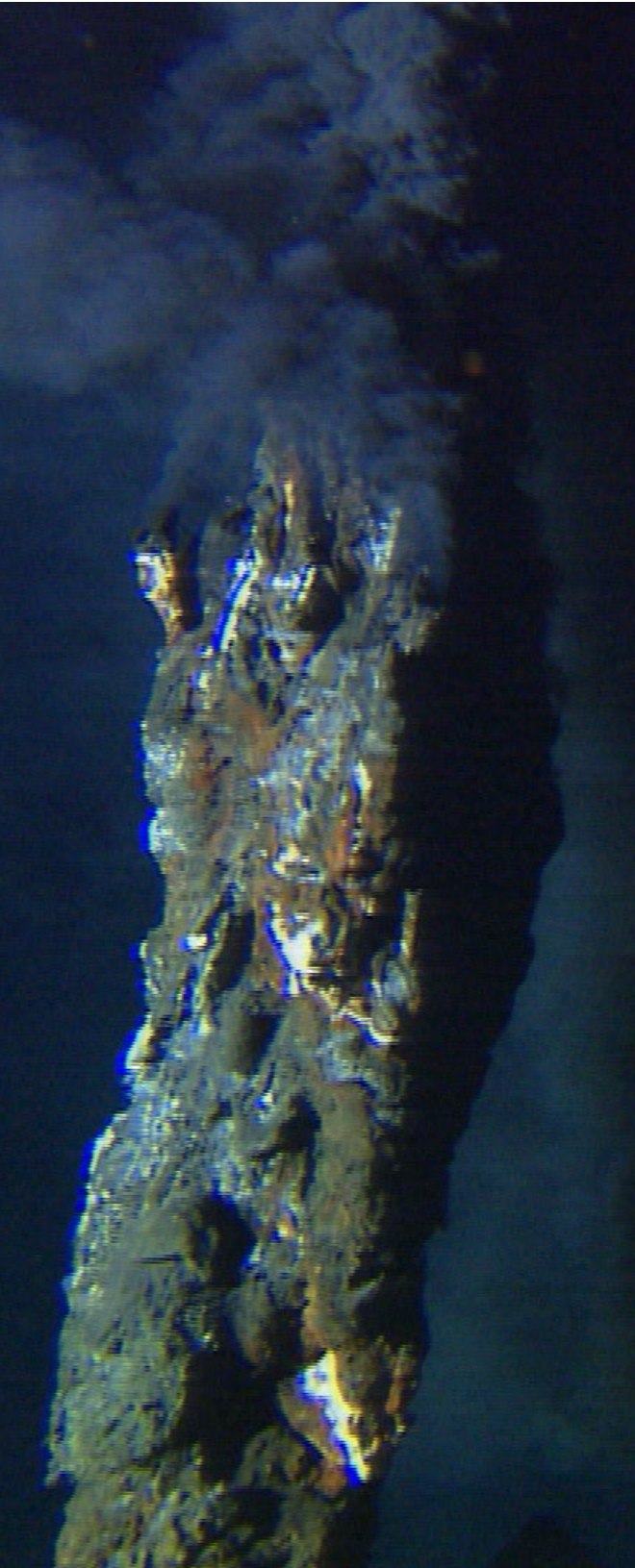
— John Collins, Jeff McGuire, and Jonathan Ware



An early-warning system for subduction zone earthquakes. The Keck-funded Ocean Bottom Seismograph (OBS) carries a broadband seismometer, strong-motion accelerometer, and tsunami detector. A computer in the OBS runs a sophisticated detection algorithm continuously on data streams from all sensors. This algorithm is designed to estimate the magnitude of a detected earthquake using just the initial few seconds of the first-arriving seismic wave. On the detection of a large earthquake, a warning is telemetered acoustically from the OBS to a nearby buoy, where it is broadcast to relevant agencies using the Iridium satellite system.

Deep-Sea Smoke

New tools for a fresh perspective on the ocean's most violent chemical reaction



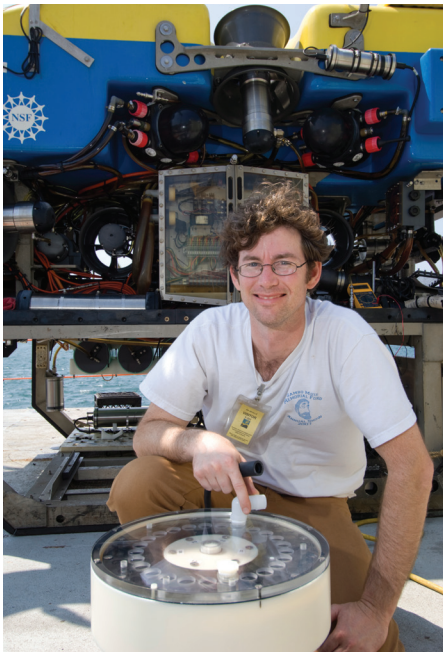
DSV Alvin, Woods Hole Oceanographic Institution

Black smoke is the hallmark of high-temperature mid-ocean ridge hydrothermal vents. The “smoke” consists of metal-rich, microscopic particles that form when super hot vent fluid is quenched by cold, abyssal ocean water. Iron and sulfur minerals such as pyrite or “fool’s gold” form first, followed by slower forming iron oxides. In addition, free floating organic debris from living organisms—and possibly abiotic or non-living organic carbon formed directly from high temperature seawater/rock reactions—become incorporated into the metal-rich particles. These particles coalesce at high-temperature vent sites and are dispersed into the ocean. Some eventually sink to the seafloor; some dissolve back into the ocean. We now suspect that some of these particles and their chemical components provide the fuel to support a microbial habitat in the water column above deep-sea vent fields.

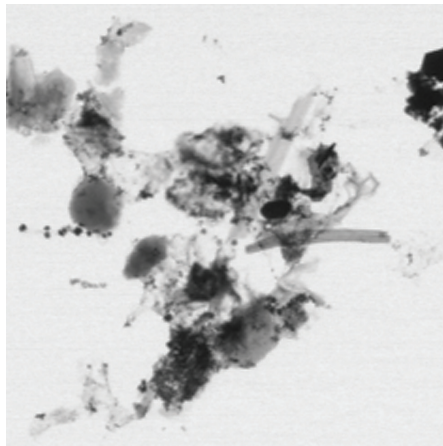
For decades oceanographers have chiefly used these particles as “smoke signals” to locate vent sites by mapping out particle concentrations in the horizontally dispersing plume that forms hundreds of meters above the seafloor. Many particle samples have been collected at vent mouths as well. These samples are the basis of our understanding of plume chemistry. Collectively, they suggest that processes active in hydrothermal plumes have a direct effect in regulating global seawater composition; but we don’t fully understand the mechanisms behind how this happens or to what extent microbial processes play a role.

What we lack are samples from the vertically rising part of the plume, where most particles form. Only a handful of these samples have ever been taken. The main obstacle has been technical: collecting particle samples from a rising hydrothermal plume with traditional oceanographic equipment is like trying to thread a needle at arm’s length. With our DOEI grant we overcame this hurdle and developed a compact, versatile, *in situ* optical-sensor-compatible particle-sampling system. The instrument, which we call a Suspended Particulate Rosette (SUPR), can systematically sample rising hydrothermal plumes from a remotely operated vehicle (ROV) like *Jason*.

We are using the novel samples we are collecting to take an unprecedented look at the structure and chemistry of hydrothermal “smoke” particles. In addition to traditional analytic techniques, Brandy Toner (now at the University of Minnesota) is using cutting-edge methods at the Berkeley Advanced Light Source to virtually



Tom Kleindinst, WHOI



Courtesy of Chip Breier, WHOI

At left, Chip Breier poses with a Suspended Particulate Rosette (SUPR), with the remotely operated vehicle (ROV) Jason in the background. Above, a sample that was collected using the SUPR.

deconstruct individual particles at a microscopic level, element by element. What we are seeing is a particle structure far more complex than previously imagined, with organic and inorganic constituents in intimate association. The samples we are collecting this summer (2008) with the *Jason* ROV at high-temperature vents on the Mid-Atlantic Ridge will help to explain how such complex structures are produced and how they affect particle/seawater reactions and microbial activity in the water column.

—John “Chip” Breier

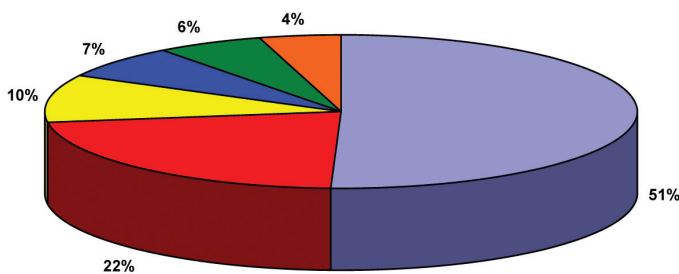
Financial Update

By June 30th, 2008, WHOI’s campaign total reached \$182,782,201. We expect to complete the \$200 million campaign by the end of this year.

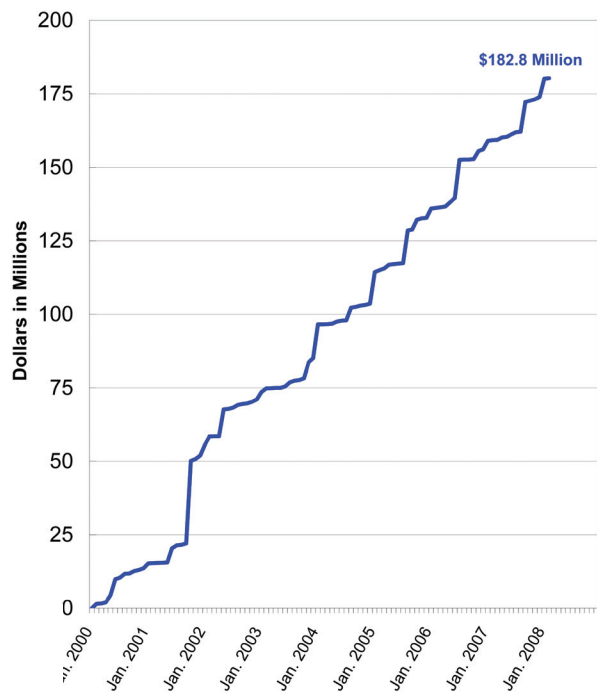
DOEI distributed \$5.7 million in funds between 2001 and 2008. In addition to supporting deep-sea exploration through fellowships and research projects, DOEI contributed to WHOI’s educational efforts by sponsoring the Geodynamics Seminar Series, supporting graduate students and postdocs, and fostering K-12 and public outreach via the Dive and Discover™ on-line expeditions.

We truly appreciate the support we have received from our many donors.

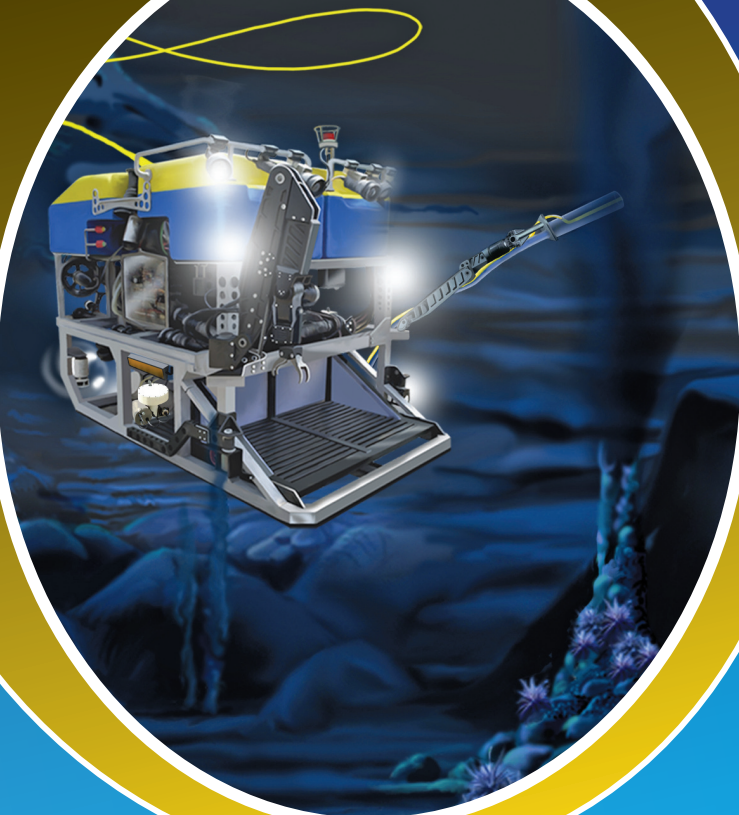
Allocation of DOEI Funds, 2001-2008



Campaign Funds Raised as of 6/30/08: \$182,782,201



■ Research Grants \$2,900,277	■ Graduate Students \$397,236
■ Fellows \$1,263,273	■ Meetings & Workshops \$338,381
■ Postdoctoral Scholars \$572,620	■ Discretionary Grants \$250,504



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
Woods Hole Oceanographic Institution
MS#22, 266 Woods Hole Road, Woods Hole, MA 02543

Dan Fornari dforfari@whoi.edu

Andrew Daly adaly@whoi.edu

Front cover: A graphical representation of the Earth and its interior. Illustration by Jack Cook, WHOI. Back cover: An artist rendering of Jason II sampling from a black smoker. Illustration by E. Paul Oberlander, WHOI.