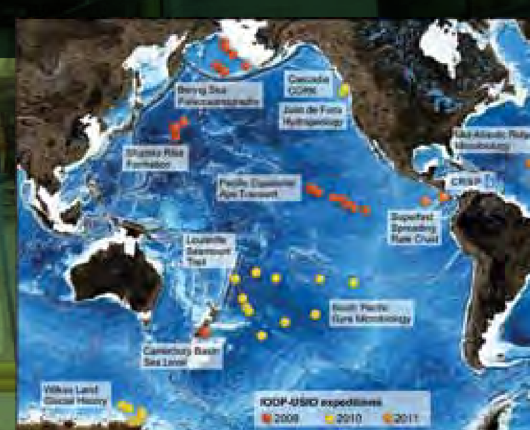
DARK ENERGY

CENTER FOR DARK ENERGY BIOSPHERE INVESTIGATIONS C-DEBI

EXPLORING THE EARTH'S DEEP BIOSPHERE

The notion of a "deep, hot biosphere" supported by geological energy sources was put forth by Thomas Gold in a 1992 essay in the Proceedings of the National Academy of Sciences (PNAS). It was a provocative idea at the time.



Top: Ocean drilling locations.

Bottom: Students explore environmental microbiology at C-DEBI summer course.

By 1998, William B. Whitman and colleagues had expanded the concept, analyzing available data on aquatic, soil, and sub-seafloor microbes. In their PNAS paper, "Prokaryotes: the unseen majority," they concluded that a significant portion of the biomass on Earth may be harbored in sediments and rock below the surface in a massive, buried biosphere of "intraterrestrial microbes."

Deep biosphere habitats exist in the dark, removed from the photosynthetic activity that fuels the surface biosphere. Energy and carbon cycling in the deep biosphere are potentially important issues in solving global energy and carbon budgets. However, studying the dark biosphere and its organic versus inorganic energy and carbon sources is very difficult, and there have been few data available about these deep ecosystems.

Compounding the challenge is the fact that most of the Earth's surface is covered by oceans, making the majority of intraterrestrial microbes only accessible by deep ocean drilling. Given the difficulty and expense of conducting such operations, little information exists about the identity of these microbial communities or the processes within the biosphere under the oceans—information that is critical to understanding the role of intraterrestrial microbes in global processes including the development and evolution of life.

Researchers at the Center for Dark Energy Biosphere Investigations (C-DEBI) have set out to tackle fundamental questions that have far reaching consequences. What is the nature and extent of life on Earth? What are the physico-chemical limits of life? How are microbes dispersed in the deep sub-seafloor biosphere? How does life evolve in deeply buried geological deposits beneath the ocean floor?

Headquartered at the University of Southern California and led by director Katrina Edwards, the center has assembled an interdisciplinary team with expertise in microbiology, molecular biology, geology, geochemistry, engineering, hydrology, among other fields, to address these questions. Partner institutions include the University of Alaska, Fairbanks, University of California, Santa Cruz, University of Hawaii, and the University of Rhode Island.

One of the roles of the center is to provide a sort of portal to the drilling activities conducted by the The Integrated Ocean Drilling Program (IODP), an international program that explores Earth's history and structure recorded in seafloor sediments and rocks. IODP is funded by six international partners, with the U.S. and Japan leading the program. The center aims to facilitate access for researchers to these drilling activities, explains James Cowen, a co-investigator of the center based at the University of Hawaii. Cowen is a member of the center's executive committee and serves as instrument and technology director for the center.

"We are at a crossroad in our quest to resolve the major questions in deep sub-seafloor biosphere research. Three new U.S.-led IODP projects for deep sub-seafloor biosphere research are poised for drilling before 2013, headed by our executive committee members and involving many of our science participants," note Edwards and colleagues."These projects developed independently, with specific sites and scientific objectives. C-DEBI will seize a unique opportunity to bundle these diverse projects to accomplish an integrated, global scientific mission. Our first major science objective is to coordinate, integrate, support, and extend the science associated with these three projects, establishing a new model for conducting internationally coordinated collaborative research in the deep sub-seafloor biosphere. C-DEBI will establish the technological, collaborative, and distributed infrastructure that is needed to effectively plan, execute, and maximize returns for deep sub-seafloor biosphere research—now and into the future."

The center aims to foster an interdisciplinary community of researchers in deep sub-seafloor biosphere research, with a focus on students and junior researchers. C-DEBI will nurture new projects through collaboration and networking between newcomers and researchers with experience in the logistical and technological know-how for mounting and executing IODP projects. In this way, the center hopes to optimize use of scarce resources and to enhance the design and development of projects that address critical global science questions.

Cowen points out there are also many opportunities for research in the center on deep biosphere studies that do not involve drilling at sea, such as studying the fluids discharged by hydrothermal vents on the seafloor. Other researchers may be involved in developing new kinds of sensors and instrumentation that can function in conjunction with drilling operations: devices to recover samples from boreholes and to perform in-situ incubation of samples, sensors such as electrochemical devices to look at fluids, and microbial scanners that can help identify and catalog organisms in drilling operations.

The Deep Exploration Biosphere Investigative Tool, for example, will provide a quick means for characterizing the distribution of microbes in subsurface matrices. This scanning capability will allow for a near in-situ assessment of biological organisms along a transect of a borehole wall. Center researchers have been testing the optical design and detection capabilities with a laboratory mock-up. Recent modeling and lab work suggests detection limit of the device may be 105 to 106 cells per cm^2.

A portable microbial scanning tool under development acts as a triage tool for spatially locating microbes that are distributed over the surface of a core. It can non-destructively locate "hotspots" of biological activity to guide prioritization, sampling, and analysis and extends the capability from borehole logging to core imaging.

C-DEBI's education and diversity objectives are to educate, inform, and translate knowledge of the deep sub-seafloor biosphere via a coordinated program across primary, secondary, and higher education programs. In the process, C-DEBI scientific participants are learning how to be more effective in communicating scientific and technical results to broader audiences. C-DEBI provides a gateway for researchers and students who originally may have been focused on biological or microbiological science to study the deep biosphere and even to cross into the disciplines of geology, physics, hydrology, genomics and more, says Cynthia Joseph, director of education and diversity for the center. □

VIEWPOINT

DIRECTOR'S VIEWPOINT

Katrina Edwards

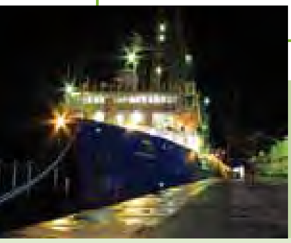
Director, C-DEBI
Professor of Biological Sciences, Earth Sciences and Environmental Studies, University of Southern California

Why drill on the sea floor?

"I think it's a tremendous opportunity for science and I think it's a tremendous boon for science exploration, which has been just really underplayed in recent years. It's really been very difficult to fund exploratory research as opposed to hypothesis-driven research. And that really goes against the human grain, you know–we're here to use our eyes and our senses every single day to explore the world around us, and it's really in our make-up to continue doing that.

The scientific future for ocean drilling has been uncertain and it's still uncertain today. Many activities that I've been involved in have been basically to promote the science of exploration. Drilling is a tool that is critical to keep in our array of exploration methods in order to further scientific research and knowledge of the world around us.

The reason to drill on the sea floor is because it represents the largest potential biome on this planet. The oceans cover seventy percent of the planet, and below that is the sub-seafloor biosphere, which is virtually unexplored. If we should ignore that, and presume that we can just focus on continental drilling, I think that would be a great leap of faith. The environments are quite different, their chemistries are quite different. The mechanism of how fluid gets into those environments is entirely different. And so I think we need to explore the largest biome on Earth for the sake of understanding it."



IODP EXPEDITION 336: "RETURN TO NORTH POND"

C-DEBI director Katrina Edwards and University of Bremen's Wolfgang Bach led this expedition during fall of 2011 to conduct experiments within the seafloor at North Pond on the western flank of the Mid-Atlantic Ridge.

Researchers and land-lubbers alike were able to follow along and learn about the expedition with Edward's blog, excerpted here. The blog was posted to the C-DEBI web site and linked to Scientific American's page on "Expeditions: Field notes from the far reaches of exploration."

About the Expedition

"… Expedition 336 takes the Integrated Ocean Drilling Program's (IODP) flagship, the Joides Resolution, to a site known as "North Pond," located the very middle of the Atlantic ocean. North Pond (22°N, Western flank) is a famous site for Ocean Drilling; originally drilled in 1975/1976 for the purposes of examining the geology of the ocean crust, this location has been studied nearly continuously for its geological, geophysical, and hydrological characteristics since first drilled.

"Now, we start a new chapter for North Pond, as well as for scientific ocean drilling: microbiological research. This expedition will be the first dedicated to study of the microbiological characteristics of the igneous ocean crust—the rocky realm that lies beneath the sediment—and will establish a long-term presence at the seafloor through the creation of subseafloor laboratories. These subseafloor laboratories are called "CORKed observatories," and are used to monitor temporal changes in the geophysical, geochemical, hydrological properties of a system and now– microbiological properties.

"CORK stands for circulation obviation retrofit kit. This is basically an acronym that was dreamed up to fit the term "CORK" because these devices effectively create a seal at the seafloor, enabling researchers to deploy instruments, experiments, and sampling devices down inside the cored borehole, that can communicate with the surface through specialized sensors and fluid umbilical lines. Deployments are designed for collection up to five years after deployment, and the physical structure that maintains the open hole may be used for decades to come. That technology now exists to permit active experiments to be conducted below the bottom of the ocean is really quite amazing, and relatively new to ocean drilling. Microbiological experiments that can be conducted include colonization experiments, perturbation experiments, isotopic experiments, and more. Only a few experiments have been deployed in CORKed observatories, and again, never before associated with a program that is dedicated to microbiological research.

"Exp. 336 is not only intending to establish CORKed observatories, but also will collect rock and sediments from below the bottom of the ocean. From these samples, scientists are planning to analyze them for their microbiological content using genetic, genomic, proteomic, biogeochemical and cultivation techniques. From analyses on these recovered materials, as well as similar analyses to be performed on recovered experimental materials from CORKs, scientists hope to learn about the what kind of microbes reside in the ocean crust and sediments, what they might be doing, and how active they are in biogeochemically important processes such as in the transformation of iron, sulfur, and carbon.

"This work, focused one of largest nearly unexplored territory on Earth, will forever change our understanding of microbial populations, their function and activities and ultimately, the consequences of their existence in the oceanic crust."

READY TO ADOPT A MICROBE?

Members of the public can get to know a microbe–up close and personal. Virtually, that is. This interactive project was designed to help raise awareness among school kids and life-long learners about the wonders of microbes living in the deep biosphere of the Earth.

Led by Beth Orcutt and sponsored by the National Science Foundation and C-DEBI, this project allows anybody to sign up to virtually “adopt” a microbe and follow along as a deep ocean project is carried out.

Adopters can take part in weekly activities and read regular posts on the project web site to learn more about microbial life Activities are designed with young kids in mind, but C-DEBI researchers hope that even adults will find them entertaining. Periodically, microbe adopters are invited to share their creative projects, such as their drawings of microbe life. Participants can watch videos, read blogs about life in the deep biosphere, and giggle at the researchers daily shenanigans while sailing the high seas, according to the project web site.

C-DEBI SUMMER COURSE FOR UNDERGRADUATES ON GLOBAL ENVIRONMENTAL MICROBIOLOGY

Undergraduate students had the chance to get their feet wet” in the field of microbial ecology and learn what bacteria are, how they work, and what they do in a four-week course sponsored by C-DEBI at the University of Southern California during summer 2011.

Lectures and labs, held at USC and at the Wrigley Marine Science Center on Santa Catalina Island, were combined with field trips to La Brea tar pits and Long Beach Aquariums.

Taught by John Heidelberg and Eric Webb of USC, this field-based, hands-on experience in microbiology and microbial ecology gave students the chance to explore DNA, genetics, and genomics and their roles in environmental systems.