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<td>Lead University</td>
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2. Changes in Faculty

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3. Primary Contact

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4. Context Statement

C-DEBI’s mission is to explore life beneath the seafloor and make transformative discoveries that advance science, benefit society, and inspire people of all ages and origins. Specifically, we seek to better understand the organisms that inhabit the sediment, rock, and fluid in the marine subsurface. Our scientific goals are pursued with a combination of approaches, through which we: (1) coordinate, integrate, support, and extend the research associated with four major programs—Juan de Fuca Ridge flank (JdF), South Pacific Gyre (SPG), North Pond (NP), and Dorado Outcrop (DO)—and other field sites; (2) make substantial investments of resources to support field, laboratory, analytical, and modeling studies of the deep subseafloor ecosystems; (3) facilitate and encourage synthesis and thematic
understanding of submarine microbiological processes, through funding of scientific and technical activities, coordination and hosting of meetings and workshops, and support of (mostly junior) researchers and graduate students; and (4) entrain, educate, inspire, and mentor an interdisciplinary community of researchers and educators, with an emphasis on undergraduate and graduate students and early-career scientists. In our education and outreach projects, we create targeted activities at several levels of engagement, with specific foci on: (1) research opportunities for community college students, (2) training and mentoring of graduate students and post-doctoral scholars, (3) professional development for K-16 instructors, and (4) broad engagement of the lay community and K-12 students through a variety of open-to-the-public events and educational partnerships.

Significant accomplishments were recorded for all 4 major programs. The final planned oceanographic expedition (AT26-18) associated with the JdF program sailed in Summer 2014 on the R/V Atlantis. Operational accomplishments included servicing borehole observatories, collecting temperature and pressure data, and sampling fluids. Scientific accomplishments included, among others, the completion of 10 manuscripts with new findings in hydrogeology, biogeochemistry, and microbiology. Major technical accomplishments were the recovery of several downhole instrument strings, which contained key environmental data and microbiological samples, and the sampling of large volumes of crustal fluids with the GeoMICROBE sled.

No new expeditions visited SPG in 2014, but the output of scientific findings continued. Five new publications featured the discoveries that a) microbial cells and aerobic heterotrophy persist throughout the entire sediment column to basement, b) radiolytic hydrogen production in seawater and sediment can be experimentally quantified, c) the slowly accumulating and oligotrophic sediment is a sink for ocean phosphate, d) rare taxa in the ocean are often abundant taxa in the underlying anoxic sediment, and e) anaerobes in the sediment use most of their available energy for biomass synthesis from performed building blocks, rather than de novo synthesis from inorganic compounds.

An ROV expedition to NP in April 2014 sampled CORK fluids, and recovered and deployed seafloor experiments. Operational and technical accomplishments with ROV Jason2 included sampling, monitoring, and servicing several observatories, and instrumenting wellheads for time-series studies. Scientific accomplishments include a) the first characterization of an active microbial community in the crustal fluids, b) description of dissolved organic matter (DOM) in sediments and crustal fluids, and c) coupled microbiological, geochemical, and mineralogic examination of subseafloor rocks and sediments.

DO was visited by two expeditions in a little over a year, in December 2013 with ROV Jason and AUV Sentry and in December 2014 with submersible Alvin. Operational and technical accomplishments included locating and sampling numerous low-temperature springs, measuring heat flow, conducting surveys for high resolution maps, and operating three platforms (ROV, AUV, elevator) simultaneously. Scientific accomplishments are just starting to materialize, including data on fluid composition, temperature, nitrate and oxygen consumption rates, microbial community compositions, and fluid flow rates.

During this reporting period, over $1.8M was invested in competed research grants and graduate and postdoctoral fellowships, many of which supported C-DEBI projects outside the 4 major programs. Of particular note is C-DEBI participation and leadership in several recent and upcoming drilling/coring/sampling expeditions. These include coring of ancient sediment in the North Atlantic; surveying trench, flank, and off-axis venting sites in Guaymas Basin, Gulf of California; studying iron-oxidizing bacteria at hydrothermal vents along the submarine Ring of Fire in the Pacific; coring sediment across the last glacial-interglacial cycles in the Baltic Sea Basin; investigating viruses and microorganisms within subseafloor basement rock at Axial seamount on the JdF Ridge; and planning IODP Expedition 357 to the Atlantis Massif to study off-axis, serpentinite-hosted hydrothermal activity and microbiology, exemplified by the Lost City Hydrothermal Field.

C-DEBI's mailing list counts approximately 1000 individuals in nearly 30 countries. Of these, over 300 are 'active' participants, defined as those who presented at one of our workshops or conference sessions, submitted proposals to C-DEBI, served on one of our committees or panels, or otherwise engaged directly in C-DEBI science or education activities. Our focus on junior researchers is nicely
demonstrated by the fact that 30 graduate and postdoctoral fellowships were active during this reporting period. Our commitment to growing research and education on life beneath the seafloor is demonstrated by the fact that almost 90 individuals received funding this year through the C-DEBI grants and fellowships program.

C-DEBI’s education and outreach program focused on several activities. Some of these activities were led by C-DEBI staff at USC, and others were carried out through institutional partnerships across the country. One of the center-led activities was a non-residential Research Experience for Undergraduates (REU)-style pilot program for gifted community college students. This program expanded to UCSC in 2014, and we are in the planning stages to further expand to the east coast. To build on its success, PI Amend and Education Director Schroeder submitted a revised NSF-REU proposal earlier this year entitled *Community College Cultivation Cohort (C4)*; a funding decision is pending. C-DEBI also operated the Global Environmental Microbiology (GEM) program, a field-based, hands-on, four-week immersion course for early undergraduates, especially those from underrepresented groups. Our partnerships in education and outreach included our co-sponsoring of teacher workshops (e.g., MBARI’s EARTH program and online programs for community college instructors), and a small grants program for teachers.

The C-DEBI renewal proposal was submitted on 1 August, 2014, requesting another 5 years of funding (Phase II). If successful, we will retain the parts of the Center that are most successful, but also make substantive changes in several key areas. Notable carry-overs to Phase II include C-DEBI’s leadership role in drilling and non-drilling field expeditions, and our commitment to investigating microbial processes in their geochemical and hydrological contexts. We will, however, balance our field work with laboratory experiments and numerical modeling, permitting broader data integration and synthesis. This requires adding new, complementary expertise to our group of senior leads, especially in microbial ecology (see Section II.1 below).

**II. RESEARCH**

1. **Overall Research Goals and Objectives**

   C-DEBI’s central research goal is to investigate the marine deep subsurface biosphere. Little is known about the physiology, phylogeny, distribution, limits, and activity in the sediments, rocks, and fluids that make up this very large biome. C-DEBI seeks to generate knowledge in this area by addressing key questions, which include:

   - What are the nature and extent of life in the subseafloor?
   - What are the physico-chemical limits of life in the subseafloor?
   - How metabolically active is the subseafloor biosphere?
   - What are the dominant redox processes in the subseafloor?

   Since the start of C-DEBI operations in October 2010, our research efforts have been focused on three major programs at the Juan de Fuca Ridge Flank (JdF), the ocean floor below the South Pacific Gyre (SPG), and a site in the North Atlantic called North Pond (NP). In 2013, we added the Dorado Outcrop (DO) in the eastern equatorial Pacific as a fourth major program, and we started to further diversify our research portfolio to include other field sites (on a smaller scale) and approaches. Targeted studies at non-major program sites are discussed in Section 2.i (Other Projects). To achieve our objectives, C-DEBI directed the bulk of the research funds to our major programs; this included ‘line-item’ funds to Co-Investigators, competitively awarded research grants, and graduate student and post-doctoral fellowships. The research diversification was accompanied by a shift resource allotment. For example, C-DEBI research focused on more targeted biomolecular analysis (e.g., metagenomics, single
cell genomics, functional gene surveys, transcriptomics, proteomics) of samples and data from past or imminent expeditions.

During the first 4+ years of C-DEBI, our research efforts were guided by four main themes:

- Activity in the deep subseafloor biosphere: function and rates of global biogeochemical processes.
- Extent of life: biomes and the degree of connectivity (biogeography and dispersal).
- Limits to life: extremes and norms of carbon, energy, nutrient, temperature, pressure, pH.
- Evolution and survival: adaptation, enrichment, and repair.

In preparing our renewal proposal (Phase 2, years 6-10), we initiated a transition in our research framework. As noted, in Phase 1 we emphasized exploration and discovery, with research activities consequently dominated by field measurements, instrument development and deployment, and sample analysis. In Phase 2, discovery science will be balanced with hypothesis testing, data integration, laboratory experimentation, and ecosystem modeling. The strategic research transition calls for a modification of the overarching research themes and associated objectives, which will maintain highly multidisciplinary and interdisciplinary approaches, with its greatest emphasis on microbial ecology. In Phase II these will be:

**Theme 1: Fluxes, Connectivity, and Energy**—centering on subseafloor environmental conditions.

(1.1) Constrain the extent, variability, and controls on fluxes and connectivity within subseafloor biomes and between the subseafloor and the overlying ocean.

(1.2) Map the geochemical energy sources in subseafloor ecosystems at a range of spatial scales.

(1.3) Develop and test the next generation of coupled geochemical-hydrological-microbial models for subseafloor ecosystems.

**Theme 2: Activities, Communities, and Ecosystems**—emphasizing resident microbial communities.

(2.1) Determine community composition, functional potential, and patterns of natural selection in subseafloor ecosystems.

(2.2) Determine metabolic activity of subseafloor microbial communities.

(2.3) Advance understanding of subseafloor microbe-virus interactions.

**Theme 3: Metabolism, Survival, and Adaptation**—concentrating on the actions and traits of individual microbial species.

(3.1) Isolate and characterize novel bacteria and archaea from diverse subseafloor habitats.

(3.2) Examine fundamental physiology of subseafloor microbes under conditions of low growth rates and low energy flux.

(3.3) Perform adaptive evolution and long-term survival experiments with subseafloor microbes to characterize molecular genetic signatures associated with particular phenotypes.

To best accomplish the modified research agenda, five senior scientists were added to C-DEBI leadership. Joining Jan Amend (USC), Julie Huber (MBL), Steven D’Hondt (URI), Andrew Fisher (UCSC), and C. Geoff Wheat (UMiss) will be Steven Finkel (Professor Bacterial Genetics and Molecular Biology at USC with expertise in mechanisms of long-term survival and evolution), John Heidelberg (Associate Professor of Marine and Environmental Biology at USC with expertise in metagenomics and metatranscriptomics), Beth Orcutt (Senior Research Scientist at Bigelow Laboratory for Ocean Sciences with expertise in geomicrobiology of subseafloor environments), Victoria Orphan (Professor of Microbial Ecology and Geobiology at the California Institute of Technology with expertise in the application of molecular techniques, microscopy, and stable isotope techniques to anaerobic microbial processes), and Alfred Spormann (Professor of Microbial Physiology and Biochemistry at Stanford University with expertise in metabolism, physiology, and metabolic ecology of anaerobic microorganisms).
2. Research Thrust Areas

Here, we summarize the most important research accomplishments for the review period and mention noteworthy problems (if any) and our solutions to those problems. The first four subsections (2.a-d) cover the major programs at Juan de Fuca Ridge Flank, South Pacific Gyre, North Pond, and Dorado Outcrop. We provide a brief background on each major program and describe the key operational, scientific, and technical accomplishments. This is followed by four subsections (2.e-h) on our research themes: Activity, Biogeography, Limits, and Evolution. Recall that for Phase 2, as detailed in the renewal proposal, the themes have been modified to better represent the integration of field, laboratory, and modeling approaches. The last subsection (2.i) briefly highlights other research projects, including those funded through the C-DEBI grants and fellowship programs.

a. Major Program: Eastern Flank of the Juan de Fuca Ridge

**Led by:** Andrew Fisher, University of California Santa Cruz

**Background**

The Juan de Fuca Ridge flank ("JdF flank") major program focuses on links between crustal and sedimentary hydrogeology, geological structure/stratigraphy, biogeochemistry, and microbiology. This program is associated with two full-length IODP drilling expeditions (Expeditions 301 in 2004 and 327 in 2010), a short technical drilling expedition to cement borehole installations (Expedition 321T in 2009), and thirteen non-drilling expeditions using conventional ships and a submersible or remotely-operated vehicle. These field operations are only a small part of the overall technical and scientific effort, which included development, testing and deployment of numerous experimental systems; collection of data and samples from the seafloor to hundreds of meters depth; laboratory analyses and experiments using materials recovered from the field; and numerical modeling of coupled flows. These projects have involved dozens of scientists, including numerous students, postdoctoral fellows, and other young scientists, many of whom contribute to enhanced diversity in STEM degree programs and professions. Tools and methods developed as part of this program have been adapted and applied in other settings. Although an earlier stage of the JdF flank major program was launched prior to development of C-DEBI, the STC leveraged external commitments and resources, increased the interdisciplinary nature of the program, added numerous collaborators and extensive education, outreach and communication activities, and accelerated the pace of discovery and achievement.

The JdF flank major program was developed to address these major questions:

- What are the rates and patterns of fluid circulation (and associated flows of heat and solutes) through the volcanic ocean crust?
- What are the magnitude and distribution of hydrogeologic properties in the crust that allow these flows to occur?
- To what extent are regions of the volcanic crust separated into distinct physical, chemical, and biological compartments?
- How is microbial ecology related to rock alteration?
- What are relations between volcanic-hosted and sedimentary-hosted microbial systems in this setting?

These questions addressed topics of primary interest to multiple themes within Phase 1 of C-DEBI, and are central to all three of the new themes developed for Phase 2. The fundamental goals, activities and outcomes from this reporting period have not changed substantially from those originally proposed.

The JdF flank program makes use of six sealed borehole observatories (CORKs), arrayed in a "T" pattern on 3.5 to 3.6 M.y. old seafloor east of the Juan de Fuca Ridge, where thick turbidites and
hemipelagic sediments cover volcanic crustal rocks. There are volcanic rock outcrops located 6-8 km north and south of the CORK sites, where warm and reacted hydrothermal fluids vent to the overlying ocean, but the CORKs are located where circulating hydrothermal fluids (and associated microbial communities) are buried at depth below the seafloor. Five of the CORKs (at Sites 1026, U1301, and U1362) are located within 1 km of each other above a buried basement high, below 235-260 m of sediment, whereas the sixth (at Site 1027) is located below ~600 m of sediment, 2.4 km to the east.

Summary of Significant Accomplishments During Review Period

Operational Accomplishments

Oceanographic expedition AT26-18 was held in Summer 2014 on the R/V Atlantis with the submersible, Alvin, with support from NSF (OCE-1260548 to Wheat, and linked proposals to Fisher, Becker, Clark, Cowen and Edwards). This was the final field expedition associated with the JdF flank major program, as originally defined, although there are plans in development by project participants to make continued use of infrastructure and knowledge established during C-DEBI Phase 1 (described later). The primary goals of AT26-18 were to service six sealed borehole observatories (CORKs), collect samples, data and instruments, from CORK wellheads, recover downhole instrument strings from three CORKs, and complete a final set of sampling and experimental operations. By the end of the expedition, the CORKs were sealed to allow long-term recovery and stability in subseafloor conditions, and to permit researchers to use and manipulate these systems in the future. A complete listing of Expedition AT26-18 activities and preliminary results is included in the Cruise Report (posted at the C-DEBI website), and summarized briefly herein.

During Expedition AT26-18, we:

• Downloaded pressure data from Holes 1027C, 1301A, 1362A, and 1362B
• Made temperature measurements in venting fluids at Holes 1026B, 1362A, and 1362B.
• Collected discharging fluids using squeezer, gas-tight, and titanium (major) samplers at Holes 1026B, 1362A, and 1362B, and made a bio-swap of the wellhead in Hole 1362A.
• Collected Formation (borehole) fluids and microbial samples were collected using large-volume pumping systems on the GeoMICROBE sled from Holes 1362A and 1362B.
• Recovered a flowmeter and closed a large-diameter ball valve at Hole 1362A.
• Recovered wellhead Osmosampler systems from Holes 1026B, 1301A, 1362A, and 1362B.

Expedition AT26-18 also completed three downhole instrument string recoveries in Holes 1026B, 1362A and 1362B, a record for a single expedition, providing Osmosampler systems that contain up to 6 years of borehole (formation) samples (>10,000 samples), along with microbial substrate experiments, and records from autonomous temperature probes. In addition, AT26-18 researchers replaced a malfunctioning pressure logger at Hole 1027C, sealed holes that were opened by downhole string recovery, and left long-term Osmosamplers in place on wellheads in Holes 1362A and 1362B. Additional work included push coring for background sedimentary samples near Hole 1027C, and collection of bottom water fluids with two CTD casts.

Scientific Accomplishments

The last calendar year has been productive for the JdF flank major program, with five peer-reviewed papers and five peer-reviewed book chapters in print or in press, two graduate theses completed, 29 papers presented at national and international meetings, and six seminars presented to technical/university and general audiences. Selected scientific accomplishments associated with the JdF flank major program are presented in this order: hydrogeology, biogeochemistry, and microbiology, with the first two topics providing critical context for understanding the third.

The hydrogeology of the JdF major program site is relatively well understood compared to the other major program sites (and arguably in comparison to all other seafloor hydrothermal systems,
whether on a ridge flank, seafloor spreading center, or volcanically active seamount). But as with heterogeneous water-rock-heat systems on land, there are vexing challenges in determining the geometry of flow paths, the fraction of rock through which most of the fluid flows, rates of fluid transport, and the nature of fluid-water-rock interactions during transport. These are properties and processes that appear to differ based on the scale and type of measurement/experiment; one of the most important contributions of JdF flank major program is that it has allowed co-located and contemporaneous application of multiple tests, sampling, and measurements, so that the differences that result from scaling or methodology can be distinguished from natural variability (temporal, spatial).

During drilling in 2010 that deployed the latest generation of subseafloor observatory systems (CORKs), tracers were injected in Hole 1362B, with the intent of monitoring recovery in nearby CORKs with long-term Osmosampling systems. Analysis of sulfur hexafluoride (SF6) tracer in samples recovered from JdF flank CORKs was the basis for Nicole Neira's M.S. thesis at UCSB (completed in Fall 2014). This study shows that tracer was recovered in Holes 1026B, 1301A, and 1362A and 1362B, documenting transport at rates on the order of meters per day, with the dominant flow direction being north to south. To date samples have been analyzed only for the period of 2010-13, and only from seafloor (wellhead) samplers. These records contain gaps for the period of 2010-11 (before initial samplers were attached at Holes 1362A and 1362B) and during the period of 2011-12 (because of a delay in a planned Summer 2012 expedition, due to ship propulsion problems, resulting in "oversampling" and data loss from wellhead systems). Additional wellhead samplers containing samples from the period of 2013-14, and subseafloor samplers containing samples from the period of 2010-14, were recovered during AT26-18. Analysis of these samples should provide a longer and more continuous record, including the critical 12 months following tracer injection.

During the review period, researchers completed the first three-dimensional simulations of ridge-flank hydrothermal circulation, with coupled fluid-heat flowing between and through seamounts, to determine what controls hydrogeologic sustainability, flow rate, and the preferred flow direction in these systems (Winslow and Fisher, 2014, submitted). This study found that sustaining flow between outcrops that penetrate less permeable sediment depends on a contrast in transmittance (the product of outcrop permeability and the area of outcrop exposure) between recharging and discharging sites, with discharge favored through less transmissive outcrops. Many simulations included local discharge through outcrops at the recharge end of an outcrop-to-outcrop system, as observed at Site 1363 (south of the main JdF flank field area). In addition, smaller discharging outcrops sustain higher flow rates than do larger outcrops in these simulations, which helps to explain how so much lithospheric heat is extracted on a global basis by this process, and why fluid fluxes are so large.

A review paper on the hydrogeologic properties and alteration patterns in ridge flank settings (Fisher et al., 2014) highlights work at both the JdF flank and North Pond major program sites (and at other drilling sites around the globe). This study finds strong lithologic and hydrogeologic control on the nature of water–rock interactions, with hydrogeology following crustal architecture and history. Permeability is generally greatest in the upper crust, but is heterogeneously distributed with depth and (at least in the JdF field area) may be azimuthally anisotropic. There appears to be a spreading rate dependence of basic patterns of rock alteration in the upper oceanic crust, with more variable and extensive alteration observed in crust created at slow- and medium-rate spreading centers. There may also be a spreading rate dependence of hydrogeologic properties, but there are not enough studies across a range of spreading rates to test this hypothesis. The evolution of crustal properties with age is consistent with sustained ridge-flank water–rock interactions to considerable crustal age (well beyond the canonical 65 M.y. "sealing age" commonly assumed), and a continued dependence of properties on fluid flow rates and reaction temperatures. Additional review papers highlighted initial characteristics of subseafloor microbiologic communities in the JdF flank and other field areas (Orcutt et al., 2014; Takai et al., 2014; Teske et al., 2014).

Lin et al. (2014) analyzed high quality borehole fluid samples collected from CORKs in Holes 1301A, 1362A, and 1362B, finding enriched concentrations of hydrogen (0.05–1.8 µmol/kg), suggesting that the ocean basaltic aquifer in this setting can support hydrogen-driven metabolism. These basement
fluids also contain significant amount of methane (5–32 µmol/kg), which can contribute to support for subseafloor basaltic habitats. The isotopic compositions of methane and the molecular compositions of hydrocarbons suggest that methane in the basement fluids is of both biogenic and abiogenic origins, varying among sites and sampling times. Hydrogen isotopic values in fluids from the CORK in Hole 1301A are much more positive than those found in all other marine environments investigated to date; this result is best explained by the partial microbial oxidation of biogenic methane.

A comparison of phylogenetic diversity of microorganisms from Holes 1026B (on 3.5 M.y. old seafloor) and 1025C (on 1.2 M.y. old seafloor, west of the main JdF flank major program work area) identifies groups that are common to the subseafloor (volcanic rock) biosphere, and are unique at the two sites (Jungbluth et al., 2014; based on work in Jungbluth's Ph.D. thesis, completed in Fall 2014). Cloning and sequencing of PCR-amplified small subunit ribosomal RNA genes revealed that fluids retrieved from Hole 1025C were dominated by relatives of the genus Desulfobulbus of the Delta proteobacteria (56% of clones) and Candidatus Desulfurudis of the Firmicutes (17%). Fluids sampled from Hole 1026B also contained plausible deep subseafloor inhabitants amongst the most abundant clone lineages.

Technical Accomplishments

One of the most important technical accomplishments during the last year was development and deployment of a system for recovery of borehole instrument strings from CORK observatories using the new Alvin submersible. This required use of a customized winch system on the deck of the R/V Atlantis. The winch was used the night before a dive to spool off 3 km of plasma cable with floatation at the top and a latch, weights, and additional floatation at the base. The submersible was used the following day to locate the latch at the base of the cable and floats, and connect this to the top of a CORK instrument string (via the top plug) using a modified industry latching tool. The latches holding the top plug (and instrument string) in place on the CORKs in Holes 1362A and 1362B were released from the wellhead using custom wrenches built specifically for this purpose. After the dive was complete and the submersible had been recovered, the floatation at the top of the long cable was located and recovered, and the winch was used to bring in the cable, top plug and subseafloor instrument string. Instrument strings were recovered in this way from Holes 1026B, 1362A, and 1362B. Data and samples have been extracted from these instruments and will be analyzed in the coming year.

Large-volume borehole fluid sampling objectives were accomplished during AT26-18 using the GeoMICROBE sled system, a unique set of tools developed as part of this major program. This permitted collection of hundreds of liters of high-quality fluid and microbial samples from CORK wellheads, contributing to studies of biogeochemistry and microbial ecology. An upgraded borehole pressure logging system was deployed on the CORK in Hole 1027C, and should provide another 4-6 years of high-resolution monitoring of crustal pressure dynamics.

Education and Outreach Accomplishments

During the 2014 review JdF flank collaborators published a paper (Cooper et al., 2014) describing one of the most productive education and outreach (E&O) programs run during a C-DEBI scientific expedition, in Summer 2013. During that expedition, a dedicated E&O staff ran >80 ship-to-shore events, including eight long-form programs, that attracted >2000 people in a 14-day period, and generated eight video products (posted online at Vimeo), several of which have been used extensively in subsequent teaching and seminar settings. This program was supported by a C-DEBI small grant, and facilitated by a fast bandwidth telepresence capability, which would not have been possible without considerable encouragement (lobbying, support) from C-DEBI personnel who pressed for the capability with NSF and UNOLS, made space available for supporting personnel on the expedition, and negotiated terms of use with the ship operator and crew (who were initially wary but eventually came to participate in numerous events).
Summary of Problems and how they were Addressed During Review Period

Loss of collaboration with Katrina Edwards. One of the project co-PIs for the most recent NSF grant supporting this work, Katrina Edwards, has had an increasingly difficult time contributing to project objectives in the last several years, and she passed away in 2014.

Illness and Recovery of Jordan Clark. Another of the Juan de Fuca project co-PIs, Jordan Clark, has continued to improve following brain surgery in 2013, and we were delighted that he was able to join AT26-18 in Summer 2014, and has become more engaged in oversight of Nicole Neira's research in his lab.

Non-recovery of Instrument String in Hole 1301A. Although we successfully recovered three CORK instrument strings on AT26-18, another string in Hole 1301A (a replacement, installed following recovery of the original string in 2009) that became stuck in the hole during a recovery attempt in Summer 2013, was not recovered in 2014. We brought out a newly developed "fishing tool" to use for this purpose, and it successfully snagged the cable holding the string in the hole at depth, but apparently that system was wedged against the side of the casing (probably by a loop of Spectra cable) and the cable parted during our recovery attempt.

Gaps in Tracer Record because of Expedition Delay in 2012. We are also challenged by the gaps in the tracer record caused by the Summer 2012 expedition that was postponed until Summer 2013, but remain hopeful that downhole records from CORKs in Holes 1026B, 1362A, and 1362B might help to fill these gaps.

► See more at the Juan de Fuca Ridge Major Program webpage
► See References Cited in Appendix A
► See related C-DEBI Contributed Publications in Appendix I

b. Major Program: South Pacific Gyre

Led by: Steven D’Hondt, University of Rhode Island

Background

The focus at this study site is on life beneath the seafloor in the most oligotrophic region of the world ocean - the South Pacific Gyre (SPG). IODP Expedition 329, led by Co-chief Scientists Steven D’Hondt and Fumio Inagaki, cored and logged deep-sea sediment and basaltic basement at seven SPG sites in 2010. Our present activity in this program focuses on post-expedition studies of samples and data from Expedition 329.

The primary purposes of this project are to:
• Document the nature of microbial communities and test the energetic limit to life in the most food-poor deep-sea sediment,
• Test the influence of basement age and sediment thickness on basement habitability, microbial communities, and the hydrologic evolution of crustal basalt.

This project addresses fundamental questions about subseafloor life, including the following: Is there a lower limit to life in oligotrophic subseafloor sediment? Are the communities in mid-gyre subseafloor sediments uniquely structured (how do these communities compare to those previously studied nearer to the continents)? Is the primary electron donor organic matter from the surface world or hydrogen from in situ radioactive splitting of water? Do microbial activities and composition vary with properties of the surface world, such as sea surface chlorophyll concentrations or organic flux to the seafloor? Is microbial activity sustainable in subseafloor basalt by mineral oxidation (e.g., oxidation of iron in the basaltic minerals) or other processes for tens of Myrs after basalt formation?

Answering these questions will help to achieve all four of the broader C-DEBI themes/objectives. The fundamental goals, activities and outcomes from this reporting period have not different substantially from those originally proposed.
Summary of Significant Accomplishments During Review Period

Scientific Accomplishments

In 2014, we submitted for publication our discovery that microbial cells and organic-fueled aerobic respiration persist throughout the entire SPG sediment sequence (D’Hondt et al., in review). This result indicates that there is no depth limit to microbial life in the most oligotrophic sediment of the open ocean (contrary to the long-standing paradigm of Morita and Zobell, 1955). Our manuscript builds on this discovery to predict that oxygen and aerobic communities may occur throughout the entire sediment sequence in up to 37% of the global ocean. This prediction has major implications for (i) the global nature and distribution of subseafloor life, and (ii) the chemical evolution of Earth’s mantle, volcanic systems and atmosphere. Our model’s primary predictors are sedimentation rate (a principal control on organic flux to the subseafloor sediment) and sediment thickness (the principal control on the timescale of oxygen diffusion through the sediment).

One of the primary 2014 accomplishments of the SPG program was our test of this prediction in a region far from the SPG; the shipboard results of our long-coring expedition KN223 provide strong evidence to confirm our model for subseafloor sedimentary oxygen distribution in the North Atlantic. Our post-expedition studies of KN223 samples and data will test our model’s prediction of community occurrence in deep subseafloor sediment of the North Atlantic.

The SPG program had several additional scientific accomplishments in this project year. These include (i) experimental quantification of radiolytic H₂ production in seawater and marine sediment (Sauvage et al., 2014), (ii) demonstration that the most slowly accumulating and oligotrophic SPG sediment is a net sink of dissolved phosphate from the ocean, whereas more organic-rich sediment at the edge of the SPG and outside it is a net source of dissolved phosphate (Mok et al., in prep.), (iii) demonstration that abundant bacterial taxa (97% similar 16S tags) in anoxic subseafloor sediment are commonly present as rare taxa in the overlying ocean (Walsh et al., 2014), and (iv) calculation that most energy flux to subseafloor sedimentary anaerobes may be used for building biomolecules from existing components (e.g., amino acids in the surrounding sediment), rather than for de novo biosynthesis from inorganic chemicals (D’Hondt et al., 2014).

The first result showed that radiolytic H₂ yield in seawater is the same as in distilled water (contrary to some previous studies) but significantly enhanced in wet zeolite-rich “abyssal clay”. In consequence, radiolytic H₂ may be an especially important electron donor for microbes in organic-poor abyssal clay. The second result has fundamental implications for the global marine phosphorus cycle. The third result implies that subseafloor sedimentary communities are seeded from the overlying ocean during initial sediment deposition. The fourth result has fundamental implications for subseafloor bioenergetics.

Technical Accomplishments

The primary technical advance of the SPG program in 2014 was our experimental quantification of hydrogen yields by gamma radiation in seawater and in natural marine sediment types (Sauvage et al., 2014).

Summary of Problems and how they were Addressed During Review Period

Our primary technical challenges during this reporting period have been development of appropriate techniques for quantitative experimental gamma irradiation and quantitative experimental alpha irradiation of natural wet sediment samples. We solved the problem for gamma irradiation (and undertook key gamma irradiation experiments) (Sauvage et al., 2014). We have designed a solution for quantitative experimental alpha irradiation of natural samples and expect to implement it in the next review period.

► See more at the South Pacific Gyre Major Program webpage
► See References Cited in Appendix A
► See related C-DEBI Contributed Publications in Appendix I
c. Major Program: North Pond
Led by: Geoff Wheat, University of Alaska Fairbanks

Background
The North Pond (NP) project investigates the origin, nature, and activity of microbial communities within basaltic basement below an isolated sediment "pond" located on the western flank of the Mid-Atlantic Ridge at 22°45'N and 46°05'W in 4400 m water depth. Subseafloor observatories (CORKs) were installed in the 8-Myr old basement during IODP Expedition 336 (Sept.-Nov. 2011). There, active, low temperature, oxygenated fluids advect vigorously through basaltic basement. Such a thermal and hydrologic setting is characteristic of large portions of the global ridge flank system, where a significant fraction of lithospheric heat is lost via hydrothermal processes, and the associated fluid-microbe-rock reactions significantly alter the composition of the oceans and crust. The role that microbes play in altering the physical and chemical characteristics of the crust in ridge flank settings are poorly constrained, and survey, drilling (IODP Exp 336), and observatory sampling/experimentation at NP strive to answer several fundamental questions:

- What is the nature of microbial communities harbored in young ridge flanks and what is their role in ocean crust alteration?
- Are these communities unique, particularly in comparison with seafloor and sedimentary communities?
- Where do deep-seated microbial communities come from (sediment, rock, seawater, other)?

To address these questions a series of international and collaborative field expeditions were planned. First, a site survey expedition, built upon earlier work, provided a comprehensive seismic, bathymetric, and heat flow dataset for coring operations. Next, IODP Exp. 336 recovered material (sediment and crustal rocks) and installed three borehole observatories (CORKs). Five months later (April 2012) an ROV expedition deployed another observatory (CORK-Lite), collected fluids from the CORKs, deployed experiments, and recovered pressure data. A second ROV expedition in April 2014 collected more CORK fluids, recovered seafloor experiments, and deployed some additional ones. Results completed this year from samples and data recovered during these three expeditions continue to shed light on all four C-DEBI themes.

Summary of Significant Accomplishments During Review Period

Operational Accomplishments
The NP observatory comprises that have been sampled to date are a single-level CORK in 210-m deep Hole U1382A and a three-level CORK in 335-m deep Hole U1383C. Besides harboring microbial incubation chambers, the observatories monitor hydrological and geochemical properties of subseafloor aquifers, and samples of aquifer fluids can be retrieved by remotely operated vehicles (ROV). The North Pond basement fluids have now been sampled twice- April/May of 2012 and April/May of 2014- using the Jason2 ROV of the Woods Hole Oceanographic Institution (WHOI) deployed from the German RV Maria S. Merian. During that cruise, the wellheads of the observatories were also instrumented for time-series studies of microbial and geochemical processes. ROV push-core sampling, heat flow measurements, and mapping as well as rock sampling of the slopes of the rift mountains surrounding North Pond supplemented the work program of the cruise. Time series analysis of recovered samples is on-going.

Scientific Accomplishments
Research in 2014 continued to focus on analyses of samples from the 2011 drilling leg and the 2012 and 2014 ROV programs, with investigators focusing on the sediments, basement rocks, and crustal
aquifer fluids. Accomplishments include the first characterization of an active microbial community in the cold oxic crustal aquifer and place it in the context of the surrounding ecosystems, including the sediment layer, bottom seawater, and basaltic crust (Meyer et al, in preparation). The major geochemical constituents in the formation fluids showed little differentiation from deep seawater, and microbial biomass in fluids from multiple depth horizons of the subseafloor observatory was similar to deep seawater (ca. 1 x 10^4 cells ml^-1) and dominated by Proteobacteria. However, 16S rRNA Illumina sequencing showed that while there was considerable overlap in the identity of taxa in the formation fluids and in the bottom seawater, the relative abundances of different groups reveal a distinct formation fluid bacterial community structure, likely seeded from deep seawater, basaltic rocks, and marine sediment, respectively. Incubations of basaltic formation fluids with ^13C-labeled bicarbonate or acetate revealed that potential rates of autotrophy could exceed those of heterotrophy by an order of magnitude. Collectively, these data reveal that while both heterotrophic and autotrophic microbes are present in cold, oxygenated aquifers, this environment may be selective for autotrophic lifestyles due to the scarcity of organic carbon. C-DEBI ExCom members Huber and Geoff contributed to this work, along with two former C-DEBI postdocs (Ulrike Jaekel and Julie Meyer), as well as C-DEBI Investigators Peter Girguis and Brian Glazer. Girguis et al. are leading efforts to characterize the dissolved organic matter (DOM) in both the sediments and crustal fluids of North Pond in a collaboration with Thorsten Dittmar at University of Oldenburg. While it is clear that distinct carbon pools exist in the aquifer and the sediments, the DOM in the crustal aquifer appears almost identical to that seen in background seawater, despite the fact that radiocarbon dating shows the deepest fluids are thousands of years older than both background seawater and other fluid horizons. These data suggest that carbon in the deepest aquifer is not being utilized by microbes, results that are consistent with experimental stable isotope tracing experiments. Because additional fluid samples were collected in 2014, time series analysis is currently underway to determine if the holes at North Pond have recovered since drilling took place, and how or if, the holes have changed since the fluids were first sampled in 2012. Preliminary data shows that biomass remains the same, but oxygen levels are slightly depleted, suggesting the holes may still be in recovery mode. Metagenomic sequencing and further stable isotope experimentation is currently underway on these samples. Additional work by C-DEBI and NSF supported postdocs and investigators continues to examine the microbiology, geochemistry, and mineralogy of subseafloor rocks and sediments. This includes members of the Edwards lab (postdoc Jean Paul Baquiran and student Andrew Gross, now being advised by former C-DEBI postdoc Jason Sylvan in collaboration with C-DEBI grantee Beth Orcutt) who are using molecular tools to examine the bacterial communities from rock samples and the thermistor string from 395A. Orcutt is also collaborating on a project with Feng Ping Wang that examines IODP Exp. 336 rock incubations with carbon and nitrogen substrates. Results suggest a stimulation of rock biofilm microbial growth with nitrogen additions. Current C-DEBI postdoc Carly Buchwald and C-DEBI grantee Scott Wankel are examining nitrogen isotope data in North Pond sediments, and collaborating with Girguis and former C-DEBI postdoc Brandi Reese on linking carbon, nitrogen, mineralogical, and 16S rRNA sequencing data to understand community structure and function in the sediment column. We expect multiple papers to be submitted in the first half of 2015 and synthesis of North Pond datasets to begin this spring as part of the two synthesis workshops we will hold on basement rocks and sediments. Finally, a proposal will go in in 2015 to return to North Pond to collect downhole instrumentation and collect additional samples.

The extent of international collaboration on the NP Project has been well beyond individual working relationships, such as those mentioned above. While these relationships broaden the field of expertise brought to bear on this project, we must note the significant effort that has been put forward by our German colleagues Bach and Villinger. They have provided a research vessel for each of the month-long expeditions, including the site survey expedition and the sampling of the CORKs in 2012 and 2014 – a cost of ~$3M. They continue to provide data and insight to rock alteration and hydrologic processes and will be involved in synthesis and integration across datasets.
Technical Accomplishments
The North Pond program continues to push technology in areas of low microbial activity and the advancement of CORK-Lite instrumentation. During the past year Tom Pettigrew, who designed all of the CORK systems to date, was contracted to provide engineering drawing that would be suitable for deploying CORK-Lites in any of the cased legacy boreholes that have been drilled over the past 40 years. This set of drawings provides the foundation for one to sample and/or develop experiments in any one of 50 legacy boreholes to study biogeochemical processes within the basaltic crust. From this selection, one can choose an appropriate crustal setting (e.g., age, temperature, redox state of the fluids, etc) to best solve vexing questions and hypotheses related to the basaltic crust.

Summary of Problems and how they were Addressed During Review Period
Loss of Katrina Edwards. Katrina was one of the primary drivers of NP-related science for the past decade, participating as Co-Chief Scientist on three expeditions, and leading the rock microbiology program there. Her death is a tragic loss for all of us. She had various collaborative grants focused on North Pond basement microbiology, and C-DEBI leadership and associated colleagues are working with USC to ensure continuity and completion of those research programs, to the best of our abilities. This remains a work in progress, with former C-DEBI postdoc Sylvan and C-DEBI grantee and theme team leader Orcutt leading the coordination effort with USC and C-DEBI.

► See more at the North Pond Major Program webpage
► See related C-DEBI Contributed Publications in Appendix I

d. Major Program: Dorado Outcrop
Led by: Geoff Wheat, University of Alaska Fairbanks

Background
More than forty years ago Lister (1972) hypothesized that the oceanic crust is cooled by hydrothermal circulation. Within a few years came the discovery of mid-ocean ridge hydrothermal systems, black smokers, and unusual benthic communities and ecology. Even though this is a magnificent find, ~25% of the total heat loss from the Earth occurs through the transfer heat via low-temperature hydrothermal systems on ridge flanks. The yearly volumetric fluid flux of this hydrothermal flow is equal to the yearly volumetric flux of fresh water that enters the ocean via rivers. Given such a large volume of fluid flow even small chemical anomalies - from biotic or abiotic reactions - can have a great influence on the chemical composition of the Ocean. Furthermore these systems can, in theory, last for millions of years, orders of magnitude longer than their mid-ocean ridge counterparts, and may influence the evolution of subsurface microbial communities and their impact on crustal evolution. Yet, until last year, no one has sampled fluids that are typical of this massive fluid flow on Earth.

The Dorado outcrop, which overlies 23 Ma seafloor east of the East Pacific Rise and west of Costa Rica, represents a new and very different sampling opportunity. On the basis of swath bathymetry, seismic and heat flow data, and systematic pore water chemical profiles, we hypothesized that Dorado Outcrop is a location where typical ridge flank hydrothermal venting occurs. In December 2013, we embarked on an expedition to Dorado Outcrop with the ROV Jason and the AUV Sentry to map (bathymetry, backscatter, side-scan, thermal anomaly) the outcrop, measure heat flow, collect sub-bottom chirp data, locate springs, and collect fluids, rocks and sediment in support of a range of hypotheses that span and integrate geophysical and microbial topics. In December 2014 we embarked on the second expedition to Dorado Outcrop. This time we used the submersible Alvin to continue our collection of data and to make new measurements.

The Dorado Outcrop Project is part of the C-DEBI portfolio with additional funding from the Marine Geology and Geophysics (MGG) Program at NSF, which included 15 days on site with the ROV Jason and AUV Sentry in 2013 and 11 dive days with the submersible Alvin in 2014, a ~$2.5M
investment in ship and underwater assets. C-DEBI added value to this program through C-DEBI Research Grants to Bigelow Laboratories (Orcutt) and the University of Akron (McManus). In addition, six post-doctoral fellows that are working on this project are doing so with C-DEBI funding: Miami University (Briggs), Harvard University (Bertics and Vidoudez), the University of Alaska Fairbanks (Inderbitzen), Woods Hole Oceanographic Institute (Buchwald), and the University of Santa Cruz (Lauer).

Summary of Significant Accomplishments During Review Period

Operational Accomplishments

Major accomplishments at Dorado Outcrop include: (1) proving correct the hypothesis that Dorado outcrop is a regional focus of massive, low-temperature, hydrothermal discharge, (2) locating, sampling, and deploying experiments in numerous springs of low-temperature hydrothermal fluid emanating from the outcrop; (3) completion of 72 measurements of heat flow on and around Dorado outcrop, most co-located on chirp or seismic lines; (4) conducting extensive surveys from which we produced bathymetric, sediment thickness, and water column temperature anomaly maps.

These accomplishments were only possible with joint ROV Jason, AUV Sentry and elevator operations. While on site the ROV Jason was in the water 79% of the time with two 100-hr-long dives and the AUV Sentry was in the water 50% of the time. These operations represent a new mode of operation for these three platforms. For example, the AUV Sentry was launched while the ROV Jason was on the seafloor conducting sampling and measurement operations and the AUV Sentry was recovered by driving the vehicle to the ship, thus minimizing the time Jason was off the bottom.

Scientific Accomplishments

Lots of different types of digital data and samples were collected in 2013. We are in the process of augmenting this data set with additional similar data and new data types such as:

• continuous records of fluid composition and temperature from four springs,
• dissolved oxygen data from discrete and continuous platforms,
• microbial enrichment experiments, which were deployed for one year and upon recovery have visual changes,
• studies of worms that propagate on the rocks,
• additional sediment coring studies that focus on oxygen and nitrate consumption and the coupled microbial communities and processes, and
• dye experiments to assess the rate of fluid flow from individual springs.

Spring fluids are very similar in composition to that of bottom seawater. Even small chemical anomalies (~1% of the seawater value) could have a major influence on the chemical composition of the Ocean. To date we have measured discernable changes in several elements and are improving analytical techniques to achieve better resolution. These fluids have dissolved oxygen concentrations that are discernably different from bottom seawater values, suggesting reaction (biotic or abiotic) within the crust.

Technical Accomplishments

In 2013 the biggest technical accomplishments were operating three platforms at once (ROV, AUV, and elevator) and a heat flow insertion tool that allows a submersible or ROV to penetrate a heat flow probe vertically, improving the quality of the data. In 2014, we used an Aanderaa Optode for discrete measurements of dissolved oxygen and developed a dye releases manifold for assessing fluid flux. We also used other technologies that have been developed earlier as part of C-DEBI funding, such as (1) the RBR oxygen and temperature probes that were recovered from North Pond to measure temperature and oxygen in several springs for periods of days (these are now off-the-shelf items from RBR, Inc.) and (2) the software that was developed to calculate heat flow.
Summary of Problems and how they were Addressed During Review Period

There were no major issues during the reporting period.

► See more at the Dorado Outcrop Major Program webpage
► See References Cited in Appendix A
► See related C-DEBI Contributed Publications in Appendix I

e. Research Theme: Activity in the Deep Subseafloor Biosphere

Led by: Beth Orcutt, Bigelow Laboratory

The purpose of the ‘Activity’ theme is to promote an understanding of the function and rates of global biogeochemical processes in the marine deep biosphere. Through targeted support of research to quantify geographic distributions of subseafloor sedimentary respiration, rates and magnitude of microbial crustal alteration, energy sources, and carbon flow, C-DEBI enables robust analyses linking subseafloor processes to global scales and biogeochemical cycles. Postdoctoral fellows and other early career members of the Activity theme published a report in Scientific Drilling this year that identified prospects and challenges for studying activity in the subsurface, based on an IODP workshop in Florence, Italy, in August 2013. The review paper “IODP Deep Biosphere Research Workshop report - A synthesis of recent investigations, and discussion of new research questions and drilling targets” is C-DEBI Contribution 154. Members of the theme also participated in the 2014 final DEBI-RCN workshop to address issues related to the power and energy available for microbial activity in the subsurface based on geochemical profiles. Such measurements and analyses have recently been reported in C-DEBI Contributed Publications 206, 218, 226, and 229. Additional samples for activity-based measurements have been collected in the past year from the Major Program sites at North Pond (April 2014, cruise MSM20-5), Juan de Fuca (August 2014, cruise AT26-18), and the Dorado Outcrop (November 2014, cruise AT26-24), with several C-DEBI students, postdocs, and researchers involved in on-going analyses.

► See more at the Activity Research Theme webpage
► See related C-DEBI Contributed Publications in Appendix I

f. Research Theme: Extent of Life

Led by: Andreas Teske, University of North Carolina

The purpose of the ‘Biogeography’ theme is to promote an understanding of how microbial communities are structured by environmental conditions, dispersal, and transport in the deep subseafloor biosphere. Activities within this research theme were dominated by the development of a deep drilling program in Guaymas Basin, a sedimented hydrothermal model system where multiple thermal and geochemical gradients structure the subsurface microbial community. Teske and several collaborators participated in a site survey cruise to Guaymas Basin, organized by Carlos Mortera at UNAM (Mexico City), to characterize the drilling targets in IODP proposal 833 by piston coring and 2D-seismic surveys (RV El Puma, October 7-27). A total of 15 piston cores, 3-5 m long, were recovered and are undergoing biogeochemical and microbiological analysis. Mortera and Teske are also in contact with the German research team of Christian Brandt (GEOMAR, Kiel) that is planning a Guaymas site survey scheduled for June/July of 2015; both site surveys will provide the data that are required for the revision of the IODP proposal. The synthesis paper on Guaymas Basin as a model system for deep subsurface biogeography was published as C-DEBI Contribution 223 (Teske, Callaghan and LaRowe 2014). Teske’s relevant outreach activities included subsurface life talks for students and postdocs at the MBL Microbial Diversity Course (August 7, 2014), at the ECORD summer school (Bremen, Sept. 22 & 23), and onboard
of *El Puma* (Oct 24, Gulf of California). In the final year of C-DEBI, we plan to hold two synthesis workshops, which will allow for biogeographical comparisons across diverse subseafloor datasets.

► See more at the [Extent of Life Research Theme webpage](URL)
► See References Cited in Appendix A
► See related C-DEBI Contributed Publications in Appendix I

g. Research Theme: Limits of Life
Led by: Tom McCollom, University of Colorado

The focus of the ‘Limits of Life’ theme is to understand the environmental and metabolic factors that place boundaries on the distribution and abundance of life in the deep subsurface biosphere. Results of C-DEBI-funded projects as well as other recent studies indicate that the majority of the microbial community living in deep sediments, for example, exist in a metabolic state of extremely slow growth owing to severe limitations in the availability of metabolic energy sources. The main activity for the theme in 2014 was a workshop held in Los Angeles in April in concert with the final DEBI Research Coordination Network meeting on the subject of Bioenergetics. The purpose of this workshop was to bring together a small group of interested scientists from both within and outside of the CDEBI community to discuss potential strategies to study microbial metabolism under severe nutrient limitation and to help stimulate more scientific research on this critical but difficult topic. Among the themes discussed at the workshop were: To what extent can studies of microbial metabolism under “short-term” nutrient starvation conditions (i.e., several years) provide insights into survival under much more prolonged nutrient limitation in the deep subsurface, lasting many thousands of years or longer? Can existing culture methods be adapted to examine life under long-term survival conditions, or do new approaches need to be developed? What novel techniques are coming on-line that could be employed for this purpose? What are the possibilities and limitations for using “omics” data to determine what microbes are doing metabolically in the deep subsurface? Many of these themes remain active areas or research for C-DEBI scientists and were also further developed and incorporated into the C-DEBI renewal proposal.

► See more at the [Limits of Life Research Theme webpage](URL)
► See more in the [Limits of Life Theme 2014 workshop report](URL)
► See related C-DEBI Contributed Publications in Appendix I

h. Research Theme: Evolution and Survival of Life
Led by: Julie Huber, Marine Biological Laboratory

The ‘Evolution and Survival’ theme promotes research focused on selective forces acting on populations within deep subseafloor communities, discovery of novel or unique functions demonstrating adaptation to this environment, exploration of gene flow between individuals within a community and between geographically distant communities, and exploration of the microbial paleontological record that informs us as to how these communities have changed over geologic time. The main activity for this year was trying to incorporate evolutionary themes more strongly into C-DEBI research activities by building on the 2013 workshop to identify exciting new research directions relevant to evolution in the subseafloor. Three important areas identified were viruses as agents of evolutionary change in the subseafloor, how to best harness the power of genomics to understand evolution in the subseafloor, and the development of model subseafloor organisms to carry out evolutionary experiments in the laboratory. Through our small research grant and fellowship program, we are currently supporting studies of viruses in crustal fluids from the Juan de Fuca Ridge Flank and archaeal genetic exchange in rock-hosted...
biofilms, for example. We have also brought Dr. Steven Finkel into our renewal team as a senior scientist to examine long-term survival and evolution of subseafloor microbes.

► See more at the Evolution and Survival Research Theme webpage
► See related C-DEBI Contributed Publications in Appendix I

i. Other Projects

As noted above, C-DEBI has an extensive grants and fellowships program, which includes funding opportunities for small research projects, research and travel exchanges, education and outreach, and graduate student and postdoctoral fellowships. A list of all 73 funded projects active in 2014 is provided in Appendix B. The breakdown of active grants and fellowships is as follows: 29 small research projects with funding up to $50K, 3 special biomolecular grants with funding up to $150K, 15 graduate student fellowships with funding for 1-2 years, 15 postdoctoral fellowships with funding for 1-2 years, 6 education and outreach grants with funding up to $50K, 4 research and travel exchange grants that require matching funds, and 1 additional grant for projects of special interest to C-DEBI. Eighty-nine different individuals, representing 45 institutions received financial support for these projects.

While some of the grants and fellowships support research related to the major programs, many support other C-DEBI-relevant investigations. These include analyses of samples and data from other deep subseafloor sites, laboratory studies of microbial activity, instrument and method development, and investigations of analog environments. Of note is the special call for biomolecular grant proposals that sought projects using state-of-the-art biomolecular approaches. Three awards ($150k each) were made: one to PI Karen Lloyd (Assistant Professor at U. Tennessee) to study organic matter breakdown in deep sediments using gene homologue analysis of metagenomes, another to PI Alfred Spormann (Professor at Stanford) to develop a new tool for screening single cells for genome identification, and a third to PI Jason Sylvan (Assistant Professor at USC) to combine omics approaches for microbial diversity and activity in igneous basement along the Louisville Seamount Trail (IODP Expedition 330). Another special call for proposals is open now, with a proposal deadline of January 15, 2015. This call emphasizes a) synthesis and integration of datasets that link microbiological processes to environmental conditions to provide insight into microbial activity, connectivity, limits, evolution, or survival in deep subseafloor ecosystems and b) analysis of or experimentation with samples from a recent or upcoming field program with clear C-DEBI research objectives.

In addition to the four major field programs reviewed above, C-DEBI is involved in other expedition-based research as well. Here, we briefly highlight five of these projects, identifying key C-DEBI personnel involved:

**North Atlantic Sediment Coring.** The primary objectives of this expedition (24 October to 1 December, 2014) aboard the R/V Knorr were paleoceanographic in nature. However, it also represents a significant opportunity for C-DEBI collaboration in studying deep subseafloor life in very ancient sediment of a previously unexplored region. (Steven D’Hondt)

**Guaymas Basin Transect.** The main goals of this cruise (7-27 October, 2014) aboard the UNAM vessel Buque El PUMA were to carry out new seismic surveys with a focus on proposed IODP drilling locations and microbiological studies on the Guaymas trench, on the flanks, and at off-axis venting site. C-DEBI interests include the active spreading center overlain with thick organic-rich sediment that is characterized by hydrothermal alterations. (Andreas Teske)

**Submarine Ring of Fire.** The first part of this expedition (29 November to 21 December, 2014) aboard the R/V Roger Revelle will focus on the study of iron-oxidizing bacteria at hydrothermal vents. These vents are dynamic and extremely productive biological ecosystems supported by chemosynthetic microbial primary production, a research area of great interest to C-DEBI. (Jason Sylvan, Craig Moyer)

**Baltic Sea Basin Paleoenvironment.** This IODP Expedition (347) (16 September to 1 November, 2013) aboard the Greatship Manisha cored sediments from different setting in the Baltic Sea
basin that spanned the last glacial-interglacial cycles. One of four main research themes was to investigate the deep biosphere responses to glacial-interglacial cycles, with specific foci on how the phylogenetic diversity of the deep biosphere differs from that of deep-ocean communities, and whether microorganisms that presently live in the deep sediments are remnants of limnic and marine populations or the result of selection by the modern sedimentary environment. (Jan Amend, Brandi Reese)

Subseafloor Life at Axial Seamount. This Gordon and Betty Moore Marine Microbiology Initiative and NOAA/Pacific Marine Environmental Laboratory Vents Program sponsored cruise (10-19 August, 2014) aboard the R/V Ronald H. Brown to investigate subseafloor microbial and viral communities tested a new deep-sea interactive sampler to collect, incubate, manipulate, and preserve crustal fluids on the seafloor. Experiments focused on metabolism, rates, and chemical signatures of subseafloor autotrophy. (Julie Huber)

► See related C-DEBI Contributed Publications in Appendix I

3. Performance With Respect to the Strategic Implementation Plan

Our primary research goal is to produce transformative, synergistic research through an inclusive collaborative culture that crosses disciplinary and institutional boundaries and is embedded throughout the Center’s activities. C-DEBI was established with a focus on three deep subseafloor biosphere projects (“Major Programs”), helping to coordinate activities associated with these projects in collaboration with U.S. and international partners. Each of these projects seeks to complete an integrated, scientific mission to resolve the nature, diversity, extent, and activity of the subseafloor biosphere in the deep sea. C-DEBI research projects address questions applied to two distinct subseafloor biosphere environments, igneous ocean crust and overlying sediments, that have historically been studied independently. C-DEBI is led by co-PIs from five U.S. universities, but seeks to build and leverage scientific, educational, and technological partnerships with numerous U.S. and international institutions (educational, research, outreach, engineering, not-for-profit). In addition, C-DEBI seeks to develop a community of multidisciplinary collaborators, to identify promising topics, and to develop new projects that will help to advance the Center's objectives.

Target 1: The initial three Major Programs are managed, and momentum is developed in new areas, to transform understanding of subsurface life.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
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<tbody>
<tr>
<td>Support initial Major Programs</td>
<td>Met</td>
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<tr>
<td>i. Hydrogeologic Properties and Processes on the eastern flank of the Juan de Fuca Ridge (IODP Expedition 327 and related expeditions and studies)</td>
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<tr>
<td>ii. South Pacific Gyre (IODP Expedition 329 and related expeditions and studies)</td>
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<tr>
<td>iii. North Pond Subseafloor Microbiology and Hydrogeology (IODP Expedition 336 and related expeditions and studies)</td>
<td></td>
</tr>
<tr>
<td>Support 1 new Major Program</td>
<td>Met</td>
</tr>
<tr>
<td>i. Discovery, Sampling and Quantification of Flows from Cool Yet Massive Ridge Flank Hydrothermal Springs on Dorado Outcrop</td>
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<tr>
<td>Submit five additional proposals (supporting Major Programs or to complete other C-DEBI related research, education, and/or outreach)</td>
<td>Met</td>
</tr>
</tbody>
</table>
Publish 5 (in aggregate) peer-reviewed papers per Major Program | Exceeded
---|---
Publish 6 (in aggregate) method/instrument papers demonstrating new techniques and tools developed and/or applied | Exceeded

**Target 2:** The research theme areas are developed in order to grow and cross fertilize between Major Programs and facilitate the development of new projects that would not have been realized without the mechanism of the STC.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop 3 new themes based on past workshop reports and results to encourage synthesis and integration across themes and sites</td>
<td>Met</td>
</tr>
<tr>
<td>i. Fluxes, Connectivity, and Energy: centering on subseafloor environmental conditions</td>
<td></td>
</tr>
<tr>
<td>ii. Activities, Communities, and Ecosystems: emphasizing resident microbial communities</td>
<td></td>
</tr>
<tr>
<td>iii. Metabolism, Survival, and Adaptation: concentrating on the actions and traits of individual activity in the deep subseafloor biosphere</td>
<td></td>
</tr>
</tbody>
</table>

**Target 3:** Cross-disciplinary and cross-institutional training are developed and implemented through grants programs helping to expand the community of deep biosphere researchers, technologists, and educators.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status / Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Award 6-8 research small grants in semiannual RFPs</td>
<td>Pending: 3 already awarded, additional to be awarded from future proposals</td>
</tr>
<tr>
<td>Award 5-10 research exchange grants in an open call</td>
<td>Pending: 4 already awarded, additional to be awarded from future proposals</td>
</tr>
<tr>
<td>Award 6-8 fellowships each for graduate and postdoctoral fellowships in semiannual RFPs</td>
<td>Met</td>
</tr>
</tbody>
</table>

4. Plans for the Next Reporting Period

The research plans for the next reporting period remain as initially stated. Considerable progress has been made with the three initial Major Programs (which include ongoing experiments and monitoring), and the new Major Program Dorado Outcrop has been launched. The STC is also focused on synthesis and integration across themes and sites. In 2015, we are holding two “synthesis and integrations” workshops for basements and sediments. Beyond examining scientific results across a variety of sites, we will also focus on “lessons learned” from different types of sample collection, experiments, and other important points related to this.
III. EDUCATION

1. Overall Education Goals and Objectives

The goal of C-DEBI’s educational component is to create distinctive, targeted education programs to foster and train the next generation of deep subseafloor biosphere researchers. We focus on undergraduate, graduate, and postdoctoral education and professional development for these audiences, but leverage our strong educational partnerships to work with K-12 students and educators to ensure engagement at all levels. Our education goals are first and foremost to ensure the robust continued development of this new field and greatly expand it in this decade via C-DEBI.

This reporting period focused on refining and expanding specific C-DEBI educational programs. These programs target distinct sections of the C-DEBI community such as community college students and instructors, underrepresented undergraduate students, and graduate students/postdoctorals. Center staff and researchers identified strategic partners to support specific outreach objectives for each of these targeted communities. Support ranged from providing researchers to speak as guest lecturers to the integration of research and education via research opportunities for undergraduates. In each of these endeavors our priority remains to engage and impact all parts of the community with the discoveries and importance of deep subsurface biosphere research.

2. Community College, Undergraduate, and Graduate Programs

Now in its second year, the C-DEBI flagship program Community College Research Internship for Scientific Engagement (CC-RISE) continued at USC and expanded to the University of California, Santa Cruz. CC-RISE is a non-residential REU-style program, led by Education Director Stephanie Schroeder at USC and by Adina Paytan at UCSC. Eight academically-competitive community college students spent eight intensive summer weeks working in labs at USC and UCSC (four at each institution). Students spent 40+ hours in the lab, conducting research in addition to participating in professional development seminars ranging from how to read/write a scientific paper to how to apply to graduate school. Students commented that they felt prepared to succeed at a four-year university and understood the application process for applying to graduate school, as well as indicated on the post-program survey that the program met or exceeded their expectations (see the CC-RISE evaluation in Appendix C and Appendix D). All eight students transferred to four-year universities in the fall (Santa Clara University, UC Davis, UCLA (2), UCSC (2), and USC (2)). Two students presented their research at the SACNAS conference and four students presented posters at the AGU conference. A comprehensive survey of the program is currently being completed by the C-DEBI external evaluator.

C-DEBI supported a new major undergraduate research internship program targeting underrepresented minorities, the Genomics and Geology Undergraduate Research Experience (GGURE) consisting of both a part-time program during the academic year and a full-time program over 10 summer weeks (detailed in the Diversity section VI). This program builds on an 11-year effort led by renewal Senior Scientist Steven Finkel to recruit and maintain undergraduate students in STEM fields as a part of USC’s Center for Excellence in Genomic Science as part of the National Human Genome Research Institute’s Minority/Diversity Action Plan. This highly successful program (based on long-term tracking of participants over the last decade) will be adapted to emphasize genomics, geoscience and other STEM fields and continue to utilize external evaluation to assess the quality and outcome of the program.

We also continue to partner with the Agouron Institute in the International GeoBiology summer course, one of the top training courses for graduate students. This intense, multidisciplinary summer course explores the coevolution of the Earth and its biosphere, with an emphasis on how microbial processes affect the environment and leave imprints on the rock record. C-DEBI funds student participation and ensures deep biosphere content in the curriculum with C-DEBI lecturers (USC faculty
Steven Finkel, Colorado School of Mines faculty John Spear, USC postdoctoral Doug LaRowe, and C-DEBI graduate fellow at USC Mark Torres).

Based largely on the successful International GeoBiology Course, another of our flagship programs targeting underrepresented students is the Global Environmental Microbiology (GEM) course for early undergraduates (detailed in the Diversity section VI). Now in its fourth year, this field-based, hands-on, four-week program for early undergraduates was instructed by USC faculty John Heidelberg and Eric Webb with directional support by Diversity Director Cindy Joseph. Sixteen students participated in the course, many from community colleges across the country. We remain in close contact with all graduates of the course through social media and other means. As with the GeoBiology program, we strive to form a community of young researchers with this common experience and continue our mentorship of them. In addition, we are continually improving the program based on feedback from the students. The C-DEBI external evaluator is currently conducting a comprehensive evaluation of the program via surveys to former students. Both the GEM and CC-RISE programs are part of C-DEBI’s Community College Connections (CCC, detailed in the Diversity section VI), which creates a pathway for students to first learn about C-DEBI research and then be engaged in C-DEBI research.

C-DEBI material was integrated into several undergraduate courses and activities by C-DEBI scientists. Victoria Orphan (Caltech) teaches Microbial Ecology and Evolution and discusses the deep subseafood biosphere in a variety of contexts, highlighting the exploratory components: the deep biosphere as the last unexplored frontier on Earth, the sheer numbers of microbial cells, and adaptive strategies of organisms living under extreme conditions, slow growth, dormancy and implications for mutation accumulation. Esther Schwarzenbach (VA Tech) served as a guest lecturer to undergraduates at Virginia Tech and was an invited seminar speaker at the University of South Carolina. Frank Robb at the University of Maryland presented 2 three-hour lectures to an audience of graduate students, postdocs, and faculty at the Algorithmic Biology Laboratory (St. Petersburg Academic University). Theme Leader Andreas Teske (UNC Chapel Hill) presented research seminars to undergraduates, graduate students, postdocs and faculty at three institutions (National Autonomous University of Mexico, Marine Biological Laboratory, Bremen University). John Spear of the Colorado School of Mines co-directed the Agouron and C-DEBI funded International GeoBiology Course for graduate students (described above). As part of the 2014 Southeastern Biogeochemistry symposium, Jennifer Glass helped organize the two-day event at Georgia Tech.

The C-DEBI Leadership and Community mentors undergraduate students, graduate students, and postdoctoral researchers both at their home institutions. They create networking and career building opportunities for both graduate students and postdocs through conferences, participation in field and oceanographic expeditions, and encourage national and international laboratory exchanges through collaborations. C-DEBI research was also presented to other undergraduate and graduate institutions with C-DEBI Leaders as invited speakers. For example, Theme Leader Beth Orcutt was an invited speaker at Stanford University and the Carnegie Institute and is touring the nation as a 2014-2015 US Science Support Program Distinguished Lecturer. Associate Director and Theme Leader Julie Huber gave talks at Bridgewater State University (MA) and an undergraduate microbiology symposium at the United States Military Academy at West Point, and also gave invited seminars at the University of Chicago (Ecology and Evolution) and University of Minneapolis (Biotechnology Institute).
### 3. Participation of Center Students and Postdoctorals in Professional Development Activities

Since 2012, C-DEBI has formalized its Professional Development Program to include a combination of in-person workshops and an online community of ~250 graduate students and postdoctorals. C-DEBI invests in the next generation of subseafloor researchers via its fellowship program (addressed in the Research section II.2.i), funding 10-15 graduate students and postdoctorals each year. A mailing list for C-DEBI graduate students and postdoctorals including these fellows supports a private forum for participants to discuss topics pertaining to their research, professional development, and post employment/fellowship opportunities. Education Director Stephanie Schroeder also sends weekly emails to the list with information about professional development resources and employment/funding opportunities from organizations such as AGU, the National Postdoc Association, Council of Graduate Schools, and the National Association of Geoscience Teachers. Students and postdocs have participated in various professional development activities as a result of mailing list announcements, ranging from attending science communication workshops at AGU to working with high school students on a science project.

Two online seminar series are ongoing. The C-DEBI Networked Speaker Seminar Series is an opportunity for C-DEBI graduate students and postdocs to interact with the larger community. Speakers are nominated by the community and selected by ExCom. The speaker gives a live, 30-minute web seminar, followed by a Q&A. The seminars are recorded for those unable to attend and C-DEBI hosts ~3/year. This third year’s speakers included Graduate Fellow Luke McKay (UNC Chapel Hill), early career researcher and former Postdoctoral Fellow Jason Sylvan (USC), former Postdoctoral Fellow Julie Meyer (University of Florida), and former Graduate Fellow Sean Jungbluth (University of Hawaii) each viewed by 25-35 live participants. An informal webinar series for the mailing list graduate student and postdoctoral network continues to address topics ranging from how to interview to life-work balance. Seminars for the upcoming year will include how to use social media to communicate science and how to juggle being a dual-career couple.

At the C-DEBI Annual Meeting, C-DEBI collaborated with MARINE (Monterey Area Research Institutions’ Network for Education) for a joint Professional Development Workshop for graduate students and postdoctorals. The goal of the workshop was to provide students with an opportunity to explore the variety of marine science pathways, as well as prepare and practice interviewing skills with these careers in mind. Students interacted and networked with professionals from a variety of interdisciplinary science careers (policy, teaching, non-profit, etc.) via a career panel in the morning and then students practiced anticipating questions reflective of potential interdisciplinary employers and
positions in a mock interview session in the afternoon. All participants indicated that the material was presented well and they were going to use the techniques they learned in the future (see the Professional Development Workshop Evaluation in Appendix E).

C-DEBI graduate students individually participated in professional development activities at their home or local institutions. These activities ranged from working with teachers to lecturing at elementary schools. As part of a previously awarded C-DEBI E&O Small Grant, Fellow Sean Jungbluth (University of Hawaii) worked with teachers in Hawaii during an Astrobiology/C-DEBI workshop, providing lectures and activities about submersibles and subseaflor research. Fellow Alexander Michaud (Montana State University) gave a public lecture and 4 presentations to 3rd-10th graders based on his Antarctic microbiology work. Fellow Luke McKay (UNC) mentored high school students, both in his lab and remotely, while Fellow Kristin Woycheese (University of Chicago) contributed to an AGU blog post about her research. As part of a general audience outreach program, Science at the Stadium, Fellow Ryan Sibert (University of Georgia) led activities on ROV testing and deep marine science.

C-DEBI postdoctorals participated in professional development activities ranging from mentoring undergraduate students to curriculum development. Fellow Ileana Perez-Rodriguez (Carnegie) mentored two undergrads and a high school student while Fellow Olivia Nigro (University of Hawaii) mentored a community college student. Fellow Stephanie Carr (Colorado School of Mines) collaborated with the Trefny Institute for Education Innovation Summer workshop and developed microbiology-based lesson plans for both first graders and eighth graders. Fellow Katherine Inderbitzen (University of Alaska Fairbanks) taught a 3-day short course to highly motivated high school graduates about the importance of scientific ocean drilling through the National Youth Science Camp.

In addition, we continue to emphasize a comprehensive ethics policy for C-DEBI participants based on existing models starting with NSF and integrating with specific IODP and other institution policies. This sets forth a community standard to minimize and resolve conflicts effectively. The online ethics training is mandatory for all C-DEBI participants and completion by deadline is enforced.

<table>
<thead>
<tr>
<th>Activity Summary</th>
<th>Professional Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Led by</td>
<td>Dr. Stephanie Schroeder, Dr. Laura Good, Edy Rhodes, Dayton Hughes, Sean Jungbluth, Dr. Luke McKay, Kristin Woycheese, Alexander Michaud, Ryan Sibert, Dr. Ileana Perez-Rodriguez, Dr. Olivia Nigro, Dr. Grieg Steward, Dr. Stephanie Carr, Dr. Katherine Inderbitzen</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Graduate students, postdoctoral fellows</td>
</tr>
<tr>
<td>Approximate Number of Attendees</td>
<td>330</td>
</tr>
</tbody>
</table>

► See more at the [Networked Speaker Seminar Series webpage](#)
► See more at the [C-DEBI Ethics Policy webpage](#)

4. Professional Development for K-16 Instructors

Our strategy for reaching educators is two-fold: professional development opportunities for educators who wish to learn at depth about deep biosphere research and accessible activities and lesson plans for educators looking for ways to integrate the process of research and cutting-edge discoveries into their classrooms, museums, aquariaums, or other settings.

For the second year, C-DEBI partnered with experts at the Monterey Bay Aquarium Research Institute (MBARI) at the 2014 EARTH (Education and Research: Testing Hypotheses) Teacher
Workshop based at MBARI. This annual workshop brings in 20 K-16 teachers from across the country to learn about current research occurring at the institutions and how to use publicly accessible, near real-time on-line data. Co-PI Andrew Fisher and researcher Adina Paytan worked with the teachers, presenting their research and assisted in developing lesson plans based on the information.

In May and November, C-DEBI ran two full-day Community College Instructor Workshops organized by Stephanie Schroeder. The purpose of the workshops was to bring in instructors from local community colleges, introduce them to current C-DEBI research, and have the instructors brainstorm how to incorporate this new knowledge into current curricula. A total of 17 instructors (4 participated in both workshops) participated from 8 Los Angeles-area community colleges (Cerritos College, East Los Angeles College, El Camino City, Long Beach City College, Los Angeles Trade Technical College, Los Angeles Valley College, Pasadena City College, and Santa Monica College). Based on evaluations from both of the workshops (see Appendix F), all instructors indicated that they would incorporate the workshop material into their curricula (to be evaluated in a follow up survey in the Spring of 2015).

The K-12 Teacher Small Grants program is a follow up program for participants in previous C-DEBI K-12 Teacher Workshops (e.g., Wrigley Workshop, EARTH Workshop, Ali’i Workshop) to stimulate and track teacher application of workshop curriculum to students. Three grants ($2500) were awarded for 2013-2014. Teacher Elizabeth Eubanks at Pope John Paul II High School (Boca Raton, FL) and 3 female students participated at the 2014 Ocean Sciences Meeting; each student presented a poster of their individual research and at the Youth Poster Session in addition to attending lectures, workshops, and other poster sessions. Teacher Mark Friedman at Animo Leadership Charter High School (Inglewood, CA) expanded classroom activities and field experiences for 66 Marine Biology Club students as well as his own professional training; Mark purchased new microscopes and aquatic ROVs that were used on an educational, near-shore ocean cruise. Teacher Alia Thompson at Kaimuki Middle School (Honolulu, HI) led student participation in an Astrobiology Camp focused on understanding the origins of life and the exploration of planktonic microbial life and ocean floor subsurface microbes.

One of the two E&O Small Grants funded this year is to the College of Exploration for the collaborative development of online kits of educational materials and resources that community college instructors can use to teach about C-DEBI research and the deep biosphere and that will also be valuable for high school teachers. This project draws upon information and resources developed in a previous E&O Small Grant for the 2013 C-DEBI online workshop “Microbes Down Below! Exploring Life Beneath the Ocean Floor” which was specifically designed for community college instructors. Comments and evaluations from community college instructors and scientists who participated in that course will be used to provide valuable guidance. The kits will be aligned with specific community college course subjects and be produced through a collaborative process involving scientists, community college faculty, graduate students and education and technology experts.

C-DEBI researchers collaborated with K-16 instructors to introduce C-DEBI material into the classroom. Postdoctorals Benjamin Tully (USC) and Brandi Reese (USC) worked with K-12 and community college instructors to develop curricula based on their research at various workshops (C-DEBI Community College Instructor Workshop, and the C-DEBI E&O Small Grant online workshop “Microbes Down Below! Exploring Life Beneath the Ocean Floor”). As part of a C-DEBI E&O grant, Mary Kadooka led five activities ranging from curriculum development to plankton activities on four Hawaiian islands.
### Activity Summary

<table>
<thead>
<tr>
<th>Professional Development for K-16 Instructors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Led by</td>
</tr>
<tr>
<td>Dr. Stephanie Schroeder, Dr. George Matsumoto, Dr. Andrew Fisher, Dr. Adina Paytan, Peter Tuddenham, Dr. Benjamin Tully, Dr. Brandi Reese, Peter Tuddenham, Mary Kadooka</td>
</tr>
</tbody>
</table>

**Intended Audience**

General audience

**Approximate Number of Attendees**

121

- See more at the [EARTH Workshop webpage](#)
- See more at the [Teacher Small Grants webpage](#)

### 5. Targeted K-12 Programs and General Outreach

By partnering with institutions across the country, C-DEBI engaged K-12 students in a variety of activities to increase their knowledge about ocean subseafood research. Diversity Director Cindy Joseph continues to work with the Animo Charter Leadership High School through the Rising Deep Scholars laboratory experience program (detailed in the Diversity section VI). C-DEBI has also supported the High School Marine Science Camp for a third year (detailed in the Diversity section VI). This week-long program is run in partnership with the USC Wrigley Institute and USC SeaGrant programs and targets underrepresented students from across the country. C-DEBI also sponsors the USC Young Researchers Program, a 6-week research internship for local high school students (also detailed in the Diversity section VI). Co-PI Geoff Wheat launched the Seafloor Science and ROV Summer Camp for 6th-8th graders which emphasizes technology to conduct subseafood research. In addition to the camp, Wheat also led 3 ROV activities for 4th-8th graders at schools in California. Co-PI Andrew Fisher gave a presentation to elementary school children and another to the general public as part of the Leonardo Art/Science Evening Rendezvous at UCSC. As part of a C-DEBI E&O Small Grant, Mary Kadooka and teacher, Alia Thompson, led activities for 4th–9th graders, introducing C-DEBI research to the students in Hawaii. Virginia Edgecomb (WHOI) gave a classroom enrichment presentation on subsurface microbiology to high school students in addition to training one student on diversity-based analyses of subsurface samples. As part of the Colorado Springs Science Festival, Alexander Michaud conducted 4 presentations to audiences of 3rd-10th graders and also did activities with the grade groups based on Antarctic microbiology.

C-DEBI’s general outreach activities range from interactive programs that involve a wide audience to public lectures to promoting C-DEBI through popular media. One of the two E&O Small Grants funded this year is to the Consortium for Ocean Leadership to publish a children’s eBook based on C-DEBI. In support of the above E&O grant, Kevin Kurtz led a JOIDES Resolution outreach event at the Aquarium of the Pacific in Long Beach, CA. At the same event, Stephanie Schroeder and postdoctoral Brandi Reese furthered C-DEBI presence at an exhibit table dedicated to C-DEBI research explaining subseafood microbes and engaging families in C-DEBI research demonstrations. To further engage the public, C-DEBI produced a short introductory video to the Center with professional videographers at USC that was featured on NSF’s Science360 webpage. Associate Director Julie Huber also was the focus of a video created by MBL that provided an overview of the research being conducted in her lab. Theme Leader Beth Orcutt gave a press release to USC based on the December expedition to the Dorado Outcrop. Ryan Sibert promoted deep marine science education via miniROV testing at a Science at the Stadium (University of Georgia). Jennifer Glass (Georgia Tech) and Leila Hamdan (George Mason University) both provided interviews for four press releases relating to their research. Samuel Hulme’s (Moss Landing Marine Laboratories) film North Pond: The Search for Intraterrestrials, won best
documentary at the 2014 Yosemite Film Festival and honorable mention at BLUE Ocean Film Festival. This feature film documentary chronicling drilling activities and the installation of seafloor observatories (CORKs) at North Pond on IODP Expedition 336 was completed as a result of his C-DEBI E&O Small Grant. This is the only feature film ever made of an ocean drilling expedition and will provide valuable public exposure to the scientific ocean drilling program (IODP) and C-DEBI when it is publicly within the next year.

<table>
<thead>
<tr>
<th>Activity Summary</th>
<th>Targeted K-12 Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Led by</td>
<td>Dr. Stephanie Schroeder, Cindy Joseph, Linda Chilton, Kevin Kurtz, Dr. Brandi Reese, Dr. Geoff Wheat, Dr. Julie Huber, Dr. Beth Orcutt, Mary Ann Kadooka, Alia Thompson, Dr. Virginia Edgecomb, Alexander Michaud, Ryan Sibert, Dr. Jennifer Glass, Dr. Leila Hamdan, Dr. Samuel Hulme</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>General audience</td>
</tr>
<tr>
<td>Approximate Number of Attendees</td>
<td>2,233</td>
</tr>
</tbody>
</table>

► See more at the High School Marine Science Camp webpage
► See more at the Young Researchers Program webpage

6. Integration of Research and Education

The integration of research and education has been critical in C-DEBI’s educational program development. The focus of our flagship undergraduate programs, CC-RISE and GEM, is to engage students in research. We have expanded our reach by supporting renewal Senior Scientist Steven Finkel’s undergraduate research program, the Genomics and Geology Undergraduate Research Experience. These three programs not only expose students to research, but provide critical professional development seminars that train the students on how to continue on a pathway into science.

As ROVs are essential to the exploration of the deep ocean biosphere, co-PI Geoff Wheat leads a program bringing engineering and ROV activities to local students. Week-long, grade-specific, hands-on technology units have been developed and tested for grades 4-8 at the International School of Monterey. His program has now expanded to schools in Mississippi. Through his C-DEBI E&O Small Grant, Steven Moore (California State University Monterey Bay, CSUMB) has worked with middle, high school, and college students promoting ROV science. In addition, Dr. Moore, along with his students built six sophisticated ROVs and three are located at the Wrigley Institute for Environmental Studies (WIES) Wrigley Marine Science Center on Catalina Island. USC staff are trained on how to use them and they are being incorporated into WIES activities. Students from the Global Environmental Microbiology (GEM) course also used ROVs to explore the local environment by collecting marine sediment and water samples with their sampling devices and characterizing the microbial communities found in each environment via DNA extractions.

7. Performance with Respect to the Strategic Implementation Plan

Our education goal is to implement programs that integrate multidisciplinary research and education efforts across the Center to advance the educational outreach and academic training of a scientific and technical workforce. Our highest priority is to create distinctive, targeted education
programs at the K-12, undergraduate, graduate and postdoctoral levels in order to train and foster the next generation of deep subseafloor biosphere researchers. While our focus is shifting to undergraduate, graduate, and postdoctoral education, we will continue working with K-12 educators to ensure engagement at all levels. Our education goals are first and foremost to ensure the robust continued development of this new field and greatly expand it in this decade via C-DEBI.

**Target 1:** Public awareness about the deep biosphere is increased

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communicate the deep biosphere in 3-5 general audience, non-scientific publications</td>
<td>Met</td>
</tr>
<tr>
<td>Present at 5 informal science events or national education conferences</td>
<td>Met</td>
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</tbody>
</table>

**Target 2:** The total number of C-DEBI associated individuals is increased

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
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</thead>
<tbody>
<tr>
<td>Increase the number of individuals engaged in each of the three associated categories: contacts (1000 in aggregate), members (receive newsletter; 350 in aggregate), and participants (funded in some way; 85 in aggregate)</td>
<td>Exceeded</td>
</tr>
<tr>
<td>Award 16 individuals and 12 institutions C-DEBI funding ranging from small and special research grants, research and travel exchanges, postdoctoral and graduate student fellowships, E&amp;O small grants and K-12 teacher grants</td>
<td>Exceeded</td>
</tr>
</tbody>
</table>

**Target 3:** C-DEBI content is introduced into K-12 and post-secondary (community college-undergraduate-graduate) education

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop and conduct 10 varied activities and programs for K-12 classrooms, e.g., high school class visits to USC/other universities, ROV activities partnered with the Wrigley Institute for Environmental Studies and ExplorOcean, SeaGrant Summer Marine Lab Experience, and guest speakers/lecturers in classrooms or special events such as Wonderkids Workshops</td>
<td>Exceeded</td>
</tr>
<tr>
<td>Incorporate deep biosphere content in 2-3 C-DEBI and partner post-secondary programs (e.g., GEM summer course for 16 undergraduates from 2- and 4-year institutions, Community College Research Internship for Scientific Engagement (CC-RISE) for 4 students and the Agouron Institute International GeoBiology Course)</td>
<td>Exceeded</td>
</tr>
<tr>
<td>Award 2 E&amp;O small grants and 3 K-12 teacher grants to fund the development of educational opportunities and materials on marine deep biosphere topics and to support K-12 teachers who have attended a C-DEBI teacher training program and have incorporated C-DEBI content into their classrooms, respectively</td>
<td>Met</td>
</tr>
</tbody>
</table>
**Target 4:** Scientists are engaged in K through postsecondary (community college, undergraduate) education via professional development activities for teachers

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create collaborations between C-DEBI science participants and teachers in 6 professional development activities such as C-DEBI community college instructor workshops and partnered programs (e.g., EARTH teacher workshop with MBARI)</td>
<td>Exceeded</td>
</tr>
</tbody>
</table>

**Target 5:** A multi-faceted professional development program for C-DEBI affiliated graduate students and postdoctorals is developed

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support regular and varied methods for professional development exclusive to graduate students and postdoctorals including weekly mailing list postings, bimonthly webinars, and an annual retreat</td>
<td>Met</td>
</tr>
</tbody>
</table>

**8. Plans for the Next Reporting Period**

C-DEBI is committed to the continued development of broad-based, targeted education programs that train and foster the next generation of deep subsea floor biosphere researchers. Our future objectives are:

1. Ongoing outreach programs that include standards-based lesson plans and activities delivered to teachers, outreach opportunities for graduate students and postdoctorals, campus visits, and student development opportunities.
2. Strengthening of partnership with community colleges by providing cutting edge research to faculty, promotion of undergraduate course and expanding the summer research internship program.
3. Expanding the web site to include downloadable lesson plans and activities for teachers using existing partnerships with the Consortium for Ocean Leadership’s Deep Earth Academy and evolving new ways to enhance existing curriculum to coordinate with upcoming IODP expeditions.
4. Using networking, existing organizations, social networking tools and local contacts to increase the scope of C-DEBI’s impact.
5. Promotion of calls for graduate student fellowships, travel grants, and postdoctoral researchers to attract the next generation of innovative scientists.

**IV. KNOWLEDGE TRANSFER**

1. Overall Knowledge Transfer Goals and Objectives

C-DEBI is committed to facilitating the exchange of knowledge, expertise, intellectual and physical resources, experimental methods, and application of new technologies within its diverse community and between the STC and the community at large. This commitment is demonstrated through open access to tools and knowledge about experimental design; making samples and data available to potential collaborators; developing new technology that is critical to achieving STC objectives; and the
distribution of information through teleconferences, our website, workshops, meetings, newsletters, presentations, technical documents, and peer-reviewed publications. C-DEBI is also committed to mentoring and exchange of students and scientists of all ages, and extensive outreach activities with the technical and general public.

The overarching objective of the Knowledge Transfer is to disseminate C-DEBI scientific discoveries and technical advances both to scientific community and broader population has not changed; however, some of the emphasis is changing as the STC changes from a growth phase to a nurturing phase. As such, our KT goals include (1) implement effective mechanisms to facilitate intellectual exchanges between institutions of various types, (2) maintain worldwide access to C-DEBI data and information, (3) nurture a new generation of C-DEBI researchers, (4) develop and make available targeted education, public outreach, and community interactions, and (5) promote economic growth through technology development. While strong partnerships among various organizations are the basis of C-DEBI, additional institutions and partners need to continually be identified to reach the full potential for technological development and innovation.

2. Knowledge Transfer Activities and Organizations

C-DEBI knowledge transfer occurs on a near-constant basis with numerous organizations, most significantly with those highlighted in the External Partnerships section V. Here, we specifically call out knowledge transfer activities that occurred during the reporting period and focused on goals one, two, and five (implementing effective mechanisms to facilitate intellectual exchanges, maintaining worldwide access to C-DEBI data and information, and economic growth and technical development). Other forms of knowledge transfer (e.g., those involving goals 3 and 4) are covered in other sections of this report, such as classroom lectures, public presentations, the Network Speaker Series, fellowship and travel grants, professional development, workshops, conferences, field trips, GEMS, CC-RISE, and teachers-at-sea.)

One of the most effective tools for transferring knowledge to the scientific community is the publication of peer-reviewed papers. During the reporting period, 25 peer-reviewed papers, two of which were focused on education and outreach, have been published most of these publications are in primary journals appropriate for particular disciplines. In addition, C-DEBI-related work was published in five book chapters, two theses, and a ninety-minute documentary of the work at North Pond. Each of these contributions is posted on our web page and introduced to the community in a monthly newsletter that reaches ~1000 individuals globally.

C-DEBI leadership also organized and participated in numerous special sessions and workshops through scientific organizations and partners (e.g., AGU, ISME, ASM, ISSM). Consistent with previous years, C-DEBI leadership also guided activities centered on the four primary research themes (Activity, Biogeography, Limits of Life, Evolution), with workshop participation by small groups (generally 10-15 people) of established and young researchers and students. The seminal meeting is the annual C-DEBI meeting (~80 people) that provides opportunities for experienced and new C-DEBI members to report and discuss recent results, and plan for ongoing and future work.

Maintaining a worldwide access to Center data is critical to our knowledge transfer mission. Mechanisms for data dissemination are highly varied because the C-DEBI community has diverse data interests, backgrounds, and needs. Data maintenance and distribution involves environmental expeditions, laboratory experiments and manipulations, modeling studies. Data types include geochemical, hydrologic, genomics, microbial strains and activity, and model grids and inputs. During this reporting period we began implementing a data management portal that provides guided access to organizational, national, and international databases.

The C-DEBI Data Portal (C-DP) is a web-based database application built with widely used and open source components including Drupal and Apache Solr (Search Lucene). The C-DP currently includes C-DEBI-contributed publications and their associated datasets, including those submitted to
external repositories and featured datasets not known to reside in repositories (such as non-xDP, non-genomic and derived datasets), and much of their explicit and implied metadata. Current work focuses on expanding the scope of the portal to include other outputs (abstracts, presentations, education and outreach materials) and productivity metrics (e.g., personnel, institutions, events, and attributed employment). Consolidating these entities into a single portal will improve the transparency and quantification of KT impacts. Other planned features include the introduction of map filters with custom base layers (e.g., global estimates, top-down bathymetry visualizations as tiles); guided data entry, spreadsheet/XML exportable tables, revision attribution to incentivize community-driven improvement, and full integration of the portal with the main website. As the data portal software is built with open source components, we consider the data portal code and configuration to comprise a useful knowledge transfer output that could be used as a template by other STCs and similar organizations. The portal’s architecture allows the option of storing and visualization of tabular datasets via integration with software like CKAN and d3.js.

Data integration and KT with entities such as EarthCube and other NSF-sponsored data capture and archiving systems will be critical in future years. To maintain C-DEBI as a leader, the Center was one of three sponsors of the EarthCube end-user workshop ("Ocean ‘Omics’ held August 21-23, 2013 at the Wrigley Marine Institute, Catalina Island, CA). Workshop participants recognize that there is a pervasive need to facilitate analysis of large sets of genomic data that are increasingly generated through (relatively low cost) sequencing studies that are now routine in microbiological research. The computational power needed to assemble and analyze these datasets remains costly, and often inaccessible to STC community members, especially those requesting funds through the Research Grant Program and the Graduate and Postdoctoral Fellowship programs. To better serve these groups, C-DEBI will provide three avenues to progress subseafloor science. First, C-DEBI has developed and will make available a dedicated server. This server is currently operational.

We recognize that access to hardware is only a part of the technical barrier. C-DEBI also will provide personnel support that will allow a broad base of C-DEBI researchers to address questions with ‘Omics’ data. This support includes one-on-one advising to communicate “tricks of the trade” and bioinformatics workshops lead by experts who are involved in subseafloor research.

Lastly, as a Science and Technology Center, several new technological advances were made during the reporting period. These advances fall with the categories of platforms, sensors, software, and laboratory technique. As many developments take multiple years for completions, several of the reported activities are a continuation or upgrade to developments last year (e.g., syringe fluid samplers, heat flow insertion tool and software, and a web-based educational tool.). New developments include:

- a low cost ROV platform that is optimized to support undergraduate marine research projects to depth of 150 m
- a data portal to provide C-DEBI partners and other researchers access to C-DEBI products (publications, data, education/outreach, and technical documents) and to facilitate access to related research and publication products
- thin section preparation of peridotite samples collected from the Ocean Drilling Program
- new methods in testing continuous high-hydrostatic pressure (HHP) culturing system
- synthetic biology of deep subsurface organisms by synthesizing and amplifying genes from marine hydrothermal vents

At this point it is uncertain which of these technologies will expand beyond academic users. However, there two projects that potentially will make a commercial impact. On project is spearheaded by Sharon Cooper who is developing an interactive eBook to be sold on iTunes. The second potential commercial endeavor is spearheaded by Geoff Wheat. He and his group developed the Seafloor Science and ROV Summer Camp, a hands-on STEM day camp for 6th to 8th grade students. This camp was tested in 2014 and will run 6 times in 2015. The vision is to make this camp self-sustaining and to expand it to other markets.
3. Performance with Respect to the Strategic Implementation Plan

Our knowledge transfer goal is to implement effective mechanisms and pathways to facilitate intellectual exchanges between institutions of various types that will support the sharing of knowledge, information, and application of new technology.

**Target 1:** Innovations are imported/exported/shared and partnerships are developed with other fields, research institutions, industry and government

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Publish and promote scholarly activity via 10 publications</td>
<td>Met</td>
</tr>
<tr>
<td>Continue to develop research collaborations through networking at 2-3 interdisciplinary meetings and talks/posters/exhibition at 2-3 conferences</td>
<td>Met</td>
</tr>
<tr>
<td>Lead 3 C-DEBI-focused meetings or special sessions at national or international meetings</td>
<td>Met</td>
</tr>
<tr>
<td>Enhance or develop 2 new tools and sensors (e.g., low cost ROV, data portal, thin section technique, high pressure system, and synthetic biology)</td>
<td>Met</td>
</tr>
</tbody>
</table>

**Target 2:** New innovation in the field is communicated through web tools, publications, media, presentations, and educating the next generation of researchers and ocean stewards.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop web-based data portal complete with listing of resources of tools, sensors and shared-use equipment for 20 community downloads such as informational exchange related to expeditions, technology, instrument availability, and sample sharing</td>
<td>Met</td>
</tr>
<tr>
<td>Garner community involvement in the use of bioinformatics analysis capabilities developed at USC through interactions with 2 individuals in one-on-one advising sessions</td>
<td>Met</td>
</tr>
<tr>
<td>Engage 20 new undergraduates to the fields of microbiology and oceanography and mentor 10 graduate students in C-DEBI fields</td>
<td>Met</td>
</tr>
<tr>
<td>Communicate with the public through non-scientific journals via social and journalistic media (5 significant contributions)</td>
<td>Met</td>
</tr>
</tbody>
</table>

4. Plans for the Next Reporting Period

C-DEBI is planning long-range knowledge transfer activities for the next reporting period that are consistent with the current practices and those outlined in the renewal proposal, taking into account feedback from reviewers, NSF Site Review committee members and NSF personnel.
Although C-DEBI-funded technology has yet to be transferred to industry, we are monitoring webinars and are familiar with NSF programs such as AIR and I-CORPS.

V. EXTERNAL PARTNERSHIPS

1. Overall External Partnerships Goals and Objectives

Our external partnerships goal is to engage and support cross-disciplinary and cross-institutional partnerships that facilitate, augment and expand the education, training and research opportunities of Center participants.

2. Activities Conducted as Part of Partnerships

Over our first 4+ years, C-DEBI has developed several very important external partnerships, both in its research and education efforts. Of particular note on the research side are our long-standing partnerships with IODP, UNOLS, and JAMSTEC, and our growing relations with the International Continental Drilling Program (ICDP), Deep Carbon Observatory (DCO), Schmidt Ocean Institute (SOI), NASA Astrobiology Institute (NAI), and ExxonMobil. On the education side, we enter into our third year of partnership with the Agouron Institute to train graduate students and continue to leverage our strong partnerships with the USC Wrigley Institute for Environmental Studies and USC SeaGrant programs on our undergraduate and high school experiences.

IODP

The Integrated Ocean Drilling Program includes, as one of its primary focus areas, exploration and elucidation of the deep biosphere. When C-DEBI was created, our operational focus for accessing and recovering microbial materials and associated data was significantly, but not exclusively, centered on IODP Expeditions 327, 329 and 336 (part of the initial three C-DEBI major programs). These three expeditions were proposed and led by C-DEBI PIs. Other IODP expeditions have also provided important microbiological samples and data for C-DEBI investigators (e.g., Expeditions 323, 330, 331, 337, 339, 353). IODP has also benefitted C-DEBI efforts through salary, research, workshop and travel support for scientists, educators, engineers, and students, both within the US and internationally. C-DEBI continues to lead IODP deep-biosphere efforts. For example, Co-PI Steven D’Hondt and collaborators have a drilling project now in the queue for IODP scheduling (830-APL).

UNOLS

C-DEBI relies heavily on the UNOLS fleet for expeditions, particularly for CORK servicing activities and coring expeditions (such as the recently completed Knorr long-coring expedition KN223).

JAMSTEC

Members of C-DEBI collaborate closely with members of the Geomicrobiology Group (led by Fumio Inagaki) at the Kochi Institute for Core Sample Research, Japan Agency for Marine Earth Science and Technology (JAMSTEC). This collaboration takes the following forms: junior members of C-DEBI (Betth Orcutt, Brandi Reese, Jason Sylvan) have worked at Kochi to learn new laboratory techniques developed by the Geomicrobiology Group. Members of the Kochi Geomicrobiology Group collaborate closely with C-DEBI members on scientific projects, providing independent lines of evidence for joint publications (e.g., as part of C-DEBI’s South Pacific Gyre and North Pond projects). Members of the Kochi Geomicrobiology Group and C-DEBI collaborate on international expeditions (e.g., IODP
Expeditions 329 and 336; Knorr long-coring expedition KN223) and proposals for new expeditions (e.g., IODP 830-APL).

ICDP

C-DEBI is partnering with the International Continental Drilling Program on two fronts. First, C-DEBI, ICDP (and DCO) are supporting complementary aspects of proposed drill-based studies of the Oman ophiolite and its microbial communities. Second, through D’Hondt, C-DEBI is providing the on-site laboratory facility and instrumentation for an NSF-supported ICDP project in southern Illinois (Lex van Geen, PI). We look forward to closer partnership with ICDP as it strengthens its program for study of subsurface life.

DCO

The Sloan Foundation-funded Deep Carbon Observatory is organized into four research communities, including one on ‘deep life’, which is dedicated to assessing the nature and extent of the deep microbial and viral biosphere. This community, co-chaired by Mitch Sogin and Kai-Uwe Hinrichs, funds scientific networking opportunities (e.g., workshops), instrumentation and infrastructure, and two research initiatives—the Census of Deep Life (CoDL) and a project on rock-hosted communities (RHC). C-DEBI member Rick Colwell is the lead proponent of the CoDL and a member of the DCO Deep Life Steering Committee. D’Hondt is also a member of the DCO Deep Life Steering Committee and the public engagement liaison for that committee. Several C-DEBI samples have been included in the CoDL sequencing efforts [e.g., Andaman Sea (Brandon Briggs), North Pond (Beth Orcutt), Juan de Fuca CORK (Amy Smith), Louisville seamount (Jason Sylvan), Bering Sea sediment (Emily Walsh)] and many more are in the queue. DCO Deep Life Leadership and C-DEBI ExCom held a joint meeting following our Annual Meeting in October to examine potential areas of intersection moving forward. The two groups are in the planning stages for two joint workshops, one of the management and use of metadata (along the lines of MIMARKS—the minimum information about a marker gene sequences) and one on high-pressure microbiology.

SOI

The Schmidt Ocean Institute is a private foundation that serves as an oceanographic operator for the seagoing community by providing ship and vehicle time via community solicited, peer-reviewed proposals. A number of ExCom members and C-DEBI investigators have participated in cruises aboard the SOI research vessel Falkor. In 2014, C-DEBI member Brian Glazer led a research cruise to Loihi Seamount, and ExCom member Huber serves on the scientific advisory committee for the new deep-diving vehicle SOI is building. Many C-DEBI members have submitted proposals to SOI for the next round of expeditionary proposal selections and are awaiting decisions on their outcome.

NAI

‘Life Underground’ is one of the NASA Astrobiology Institute CAN-6 teams, funded in 2013. This cross-disciplinary team, led by PI Jan Amend, is using field, laboratory, and modeling approaches to detect and characterize microbial life in the subsurface—predominantly, but not exclusively, on the continents. C-DEBI and NAI are sharing key personnel, jointly developing down-hole biomass detection capabilities using deep UV microscopy, modeling microbial metabolism potential in marine sediments globally, and coordinating several education and outreach efforts.

ExxonMobil Upstream

C-DEBI (through D’Hondt) is collaborating with ExxonMobil Upstream to build on our studies of microbial diversity in deep subseafloor sediment and its relationship to microbial diversity in the surface world. This collaboration is now growing to include other C-DEBI investigators. It is also growing from a laboratory- and computation-focused study to include C-DEBI investigators in field studies.
Education

The interdisciplinary nature of C-DEBI research lends itself magnificently to a diverse array of external education partnerships. One of the primary education goals of C-DEBI is to train the next generation of deep subseafloor biosphere researchers. We partner with one of the top training courses for graduate students, the Agouron Institute International GeoBiology summer course, currently co-directed by C-DEBI funded scientist Dr. John Spear, Colorado School of Mines. Just as C-DEBI and the Agouron Institute course share key personnel (administrative and instructional), so do C-DEBI and the USC Wrigley Institute. This facilitates our training of undergraduates through programs such as the Global Environmental Microbiology course (based heavily on the successful GeoBiology program) and a growing ROV education program at the Institute’s marine lab on Catalina Island. The facility is also the sight of our high school program, run by the USC SeaGrant program, part of the Wrigley Institute. Our outreach partners have grown to include the Monterey Bay Aquarium Research Institute the College of Exploration, and other STCs (e.g., C-MORE) that enable us to train teachers at the K-16 levels.

Problems Encountered or Anticipated

The ongoing uncertainty about the U.S. future of long coring (following the retirement of the RV Knorr) is damaging for C-DEBI planning of future field activities. This uncertainty will significantly inhibit C-DEBI field opportunities unless and until NSF demonstrates its commitment to future long coring and identifies an appropriate ship for these operations.

3. Performance with Respect to the Strategic Implementation Plan

Our external partnership goal is to engage and support cross-disciplinary and cross-institutional partnerships that facilitate, augment and expand the education, training and research opportunities of Center participants. C-DEBI will implement a number of publication, proposal and training requirements as a measure of a strong cross-disciplinary and cross-institutional program that produces transformative research results. Research publication and proposal targets will include those for Center Major Programs, but also for other smaller research projects as well as those related to new techniques and tools to transform existing operating procedures. Cross-disciplinary and cross-institutional research needs will be supported by publication and proposal requirements for Major Programs and all other projects, while graduate students, postdoctorals and scientists will also directly engage in cross-disciplinary and cross-institutional training exchanges.

Target 1: Strong cross-disciplinary research projects and strong cross-institutional programs are demonstrated in all aspects of Center activities, including publications, presentations, proposals, educational exchanges, and educational programs.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Publish 5 (in aggregate) cross-disciplinary papers per Major Program with support from calls for small research and travel grants to facilitate the interaction of dispersed Center researchers</td>
<td>Met</td>
</tr>
<tr>
<td>Submit 2 cross-disciplinary and cross-institutional proposals</td>
<td>Met</td>
</tr>
<tr>
<td>Support 2 interdisciplinary workshops or meetings in concert with other national programs</td>
<td>Pending</td>
</tr>
</tbody>
</table>
Fund 8 graduate students, postdoctoral fellows and C-DEBI community scientists in their pursuit of generating data or developing cross-discipline techniques and tools to further Center objectives | Met

Fund 3 student/researchers to participate in research expeditions or travel to another institution to expand the scope of their education/research in the use of novel techniques and tools | Met

**Target 2:** Strong cross-institutional programs are demonstrated by a diversity of co-author and co-investigator home institutions.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Publish 5 cross-institutionally co-authored papers including from the small research and travel exchange grants</td>
<td>Met</td>
</tr>
<tr>
<td>Submit 3 cross-institutionally co-authored proposals by engaging the community in annual meetings and organizing meetings around research themes</td>
<td>Met</td>
</tr>
<tr>
<td>Include personnel of 5 institutions per expedition advertising opportunities to C-DEBI participants via the website, newsletters and direct emails to mailing list participants</td>
<td>Met</td>
</tr>
<tr>
<td>Fund 10 cross-institutional exchanges for students, postdoctorals and scientists who travel to another institution for sharing of techniques and tools</td>
<td>Pending: 3 already awarded, additional to be awarded from future proposals</td>
</tr>
</tbody>
</table>

**Target 3:** Partnerships are developed with other fields, research institutions and organizations, industry and government.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build 10 partnerships by networking at interdisciplinary meetings, developing industrial and governmental partners, and targeting partnerships and interactions for new applications of existing or budding technologies</td>
<td>Met</td>
</tr>
</tbody>
</table>

**4. Plans for the Next Reporting Period**

Our ongoing plan is to leverage newly created partnerships for the development of additional new partnerships in the next reporting period. We also will continue our web-based and email forms of communications to the existing and future C-DEBI partners for dissemination of information and opportunities.
VI. DIVERSITY

1. Overall Diversity Goals and Objectives

C-DEBI seeks to train a new, diverse generation of undergraduate, graduate and postdoctoral researchers within an integrated and collaborative multidisciplinary community. We are committed to improving access and support for members of underrepresented groups, women, and first-generation college students to be able to succeed in STEM fields.

2. Activities Which Enhance Diversity at the Center

C-DEBI has made gains in gender representation of our research and administrative participants (see diversity statistics below), and we continue to work toward increasing underrepresented minorities by promoting deep subsurface research through Minority Professional Organizations and national networks. This year, C-DEBI disseminated program and graduate training opportunities with partners such as the Institute for Broadening Participation (IBP), the Society for Advancing Chicanos and Native Americans in Science (SACNAS), the Louis Stokes Alliance for Minority Participation, and the broader STC Education and Diversity network. With the 2014 SACNAS Conference being held in Los Angeles, California (October 16-18), USC together with C-DEBI emphasized the importance of this conference by being a premiere sponsor. At the conference, C-DEBI sponsored two sessions; volunteers led tours of the Amend and Finkel labs; and several of our faculty, postdoctoral fellows, students, and staff were presenters, exhibitors, and judges. In addition, C-DEBI created a joint STC brochure promoting graduate school education at nine conference-attending STCs, and the Center’s research and education opportunities were advertised through the STC Tribal Network REU program and the Geoscience Alliance.

<table>
<thead>
<tr>
<th>C-DEBI Research and Administrative Participants</th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty (20)</td>
<td>35%</td>
<td>65%</td>
</tr>
<tr>
<td>Other Research Scientist (4)</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Postdoctoral (22)</td>
<td>59%</td>
<td>41%</td>
</tr>
<tr>
<td>Graduate Student (28)</td>
<td>54%</td>
<td>46%</td>
</tr>
<tr>
<td>Undergraduate (10)</td>
<td>60%</td>
<td>40%</td>
</tr>
<tr>
<td>Other Participant (13)</td>
<td>69%</td>
<td>31%</td>
</tr>
<tr>
<td>Staff (6)</td>
<td>83%</td>
<td>17%</td>
</tr>
<tr>
<td><strong>Total (103)</strong></td>
<td><strong>55%</strong></td>
<td><strong>45%</strong></td>
</tr>
</tbody>
</table>
**C-DEBI Research and Administrative Participants**

<table>
<thead>
<tr>
<th></th>
<th>White (all ethnicities)</th>
<th>White, Hispanic/Latino</th>
<th>Native Hawaiian or Other Pacific Islander</th>
<th>Asian</th>
<th>African American</th>
<th>Native American</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty (20)</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Other Research Scientist (4)</td>
<td>75%</td>
<td>0%</td>
<td>0%</td>
<td>25%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Postdoctoral (22)</td>
<td>95%</td>
<td>0%</td>
<td>0%</td>
<td>5%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Graduate Student (28)</td>
<td>82%</td>
<td>11%</td>
<td>0%</td>
<td>7%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Undergraduate (10)</td>
<td>60%</td>
<td>10%</td>
<td>0%</td>
<td>20%</td>
<td>10%</td>
<td>0%</td>
</tr>
<tr>
<td>Other Participant (13)</td>
<td>77%</td>
<td>0%</td>
<td>0%</td>
<td>8%</td>
<td>8%</td>
<td>8%</td>
</tr>
<tr>
<td>Staff (6)</td>
<td>66%</td>
<td>17%</td>
<td>0%</td>
<td>17%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Total (103)</strong></td>
<td><strong>85%</strong></td>
<td><strong>5%</strong></td>
<td><strong>0%</strong></td>
<td><strong>8%</strong></td>
<td><strong>1%</strong></td>
<td><strong>1%</strong></td>
</tr>
</tbody>
</table>

C-DEBI continues to build on program successes of the past three years by expanding and evaluating for continuous improvement four distinct projects targeting underrepresented minorities, women, and first generation and low-income students: the Global Environmental Microbiology (GEM) course, Rising Deep Scholars, Community College Connections, and the Genomics and Geology Undergraduate Research Experience (GGURE). The summer of 2014 boasted the most diverse group of GEM course undergraduates from 2- and 4-year colleges. This course teaches students through field-based research and laboratory analysis. Students create hypotheses, analyze data, and present their findings throughout the course. The course’s external evaluation is in Appendix G. Continuing in partnership with Animo Leadership Charter High School, three Rising Deep Scholars joined a team of C-DEBI graduate students to conduct academic year lab internships engaging them in microbiological lab techniques. Rising Deep Scholars from 2010 and 2011 are all now pursuing STEM degrees at four-year universities. The Community College Connections program expanded to 2 new schools in the Los Angeles area and added participation of UCSC students as STEM Seminar speakers at Hartnell College in Central California. Introductory seminars at two-year colleges and subsequent campus visits broaden student knowledge of research’s role in society, introduce C-DEBI investigations of the life buried in subseafloor sediment and rocks, and identify pathways to advanced degrees in STEM fields. Our weekly blog, Sci-Curious, continues to engage all students in scientific discovery and promotes retention and persistence strategies. C-DEBI has added a new lab internship program, GGURE, directed by renewal Senior Scientist Dr. Steven Finkel at USC that entrains undergraduates in Genomic and Geobiology fields and brings 11 years of documented success to C-DEBI’s undergraduate program.

C-DEBI reaches diverse student populations through various program partnerships. We continue to engage the USC SACNAS Chapter, SACNAS leadership, and the broader C-DEBI community through scientific talks and professional development. Our partnership with the USC Young Researchers Program provided stipends and C-DEBI graduate student mentors for the locally-recruited high school students participating in a 6-week lab internship in science and engineering. Together with the USC Wrigley Institute and USC SeaGrant, C-DEBI cosponsors the High School Marine Science Camp, a 1-week hands-on, inquiry-based program for 20 diverse high school students recruited nationally. See Appendix H for detailed diversity program information.
3. Impact of Programs or Activities on Enhancing Diversity at the Center

Student demographic information and details of the following diversity programs are reported in the Diversity Program Outputs Appendix H.

<table>
<thead>
<tr>
<th>Program</th>
<th>Number of Participants</th>
<th>Diversity Objective</th>
<th>Measurement of Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Environmental Microbiology (GEM) Summer Course</td>
<td>16 (63 in 4 years)</td>
<td>Hands-on experience for 2- and 4-year undergraduate students in environmental microbiology</td>
<td>External evaluation, Retrospective survey, Longitudinal tracking</td>
</tr>
<tr>
<td>Rising Deep Scholars</td>
<td>3 (9 in 3 years)</td>
<td>Research lab experience for high school students</td>
<td>Pre- and post-test, Longitudinal tracking</td>
</tr>
<tr>
<td>Community College Connection (Introduction Seminar)</td>
<td>433</td>
<td>Expand student knowledge of C-DEBI &amp; scientific research and introduce resources &amp; opportunities</td>
<td>Student sign-up, Subsequent involvement, Blog statistics</td>
</tr>
<tr>
<td>Community College Connection (day trip to campus) &amp; SACNAS fieldtrip</td>
<td>87</td>
<td>Strengthen student knowledge of C-DEBI research and programs, introduce</td>
<td>Event surveys</td>
</tr>
<tr>
<td>SACNAS Conference &amp; USC Chapter</td>
<td>3,800+</td>
<td>Inform students already in the STEM pipeline of C-DEBI specific research</td>
<td>Session data, Campus visit assessment</td>
</tr>
<tr>
<td>Young Researchers Program</td>
<td>5 (17 in 4 years)</td>
<td>Research lab experience for high school students</td>
<td>Summary report</td>
</tr>
<tr>
<td>Marine Science Camp</td>
<td>20 (59 in 3 years)</td>
<td>Hands-on exploration of oceanography for high school students</td>
<td>Summary report of survey</td>
</tr>
<tr>
<td>Genomics and Geology Undergraduate Research Experience (GGURE)</td>
<td>37 academic year; summer semester pending</td>
<td>Academic year and summer research internship program for underrepresented undergraduate students at USC</td>
<td>External evaluation</td>
</tr>
</tbody>
</table>

4. Performance with Respect to the Strategic Implementation Plan

C-DEBI implements various programs that introduce research findings to members of underrepresented groups, thereby strengthening the STEM pipeline. We aim to increase the racial, ethnic, and gender diversity of C-DEBI participants and of science and technology practitioners in general. To
better communicate our science to members of underrepresented groups, we partner with educators and organizations that bring training opportunities and educational content to K-12, junior colleges, undergraduate and graduate programs.

**Target 1:** The diversity of participants in all levels of C-DEBI from undergraduate, graduate and postdoctoral to participating researchers and staff is increased.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Promote C-DEBI research opportunities to diverse audiences through 3 different partners and 2 new partners to increase the diversity of graduate students and postdoctorals across the center</td>
<td>Met</td>
</tr>
</tbody>
</table>

**Target 2:** Programs that target underrepresented students and engage them in STEM fields are developed and implemented.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop or expand 1 program each year to attract underrepresented students into STEM fields</td>
<td>Met</td>
</tr>
</tbody>
</table>

**Target 3:** Partnerships are initiated with other organizations, institutions, programs, or informal science centers that target underrepresented students and engage them in STEM fields of study.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduce C-DEBI science with appropriate resources and training to 1 institution and/or educator that primarily serves underrepresented groups</td>
<td>Met</td>
</tr>
</tbody>
</table>

**5. Plans for the Next Reporting Period**

Our future goals are to:
1. Strengthen partnerships with local community colleges by identifying undergraduate students interested in geoscience careers from programs and partners and graduate students and/or postdoctorals willing to participate in a virtual mentoring program
2. Actively encourage undergraduates to progress to graduate school in areas of deep subsurface research by promoting summer research or intensive programs being led at C-DEBI networked institutions
3. Continue to leverage support services and potential connections, organizations and institutional resources within partnering Universities to promote diversity
4. Actively promote all opportunities throughout the Center to underrepresented groups and recruit at all levels of Center activity
5. Inform and encourage the C-DEBI community to participate in conferences and outreach that engages them with underrepresented students to promote recruitment into C-DEBI fields
6. Continue to leverage 2014 SACNAS involvement to promote and provide financial support to undergraduate and graduate students from C-DEBI to present research at the annual SACNAS conference
7. Continue support and mentoring for the USC SACNAS Chapter linking them to SACNAS Chapters at C-DEBI partnering institutions and SACNAS leadership.

VII. MANAGEMENT

1. Overall Organizational Strategy

Our management plan facilitates the achievement of the principal scientific, education, and diversity goals of C-DEBI. C-DEBI management is composed of these major leadership groups: Directorship; Executive Committee; Administration; Research; Knowledge Transfer, Data Management and Integration; and Education, Outreach and Diversity. The major advisory groups for C-DEBI are the External Advisory Board; Ethics Panel; External Evaluator; and the Education & Outreach Steering Committee. We maintain a simple hierarchy in the management structure (rectangles below) with several advisory groups (ovals below) to encourage communication and collaboration, as well as provide transparency in decision-making. Their roles and interactions are described below and further detailed in our Operations Manual.

Directorship

The Center is led by the Director, PI Jan Amend (USC), and the Associate Director, Julie Huber (MBL), both members of the Executive Committee. The Director is responsible for overall C-DEBI coordination and performance. He provides leadership in C-DEBI scientific, education, diversity, outreach, and administrative activities; he represents C-DEBI in interactions with USC administration and funding agencies; and he promotes the Center worldwide. The Director works closely with the Managing Director at USC.

The Associate Director is the ‘right hand’ of the Director; she assumes all responsibilities and powers of the Director should he, for any reason, be unable to carry out his duties. Together with the Managing Director, she coordinates the grants program and communicates with grant recipients about outcomes, products, and dissemination of results.

Executive Committee (ExCom)

The Executive Committee (ExCom) manages, supports and leads the direction of the Center’s science initiatives, including the major programs (currently: South Pacific Gyre, Juan de Fuca Ridge Flank, North Pond, and Dorado Outcrop). ExCom also provides guidance to integrate research, education, and data across the Center. ExCom coordinates with the Theme Team Leaders on C-DEBI research directions. Formerly, the Theme Leaders developed the Requests for Proposals and supplied review recommendations; currently ExCom generates calls for proposals and serves as the review panel, with mechanisms to avoid conflict-of-interest.
ExCom consists of five members: Director Jan Amend (USC), Associate Director Julie Huber (MBL), Steven D’Hondt (URI), Andrew Fisher (UCSC), and C. Geoffrey Wheat (U Alaska-Fairbanks). Co-PI Fisher leads the Juan de Fuca field program, and Co-PI D’Hondt leads the South Pacific Gyre field program. Co-PI Wheat leads the North Pond and Dorado Outcrop field programs and also serves as Knowledge Transfer Director. Huber also served as the liaison between ExCom and the Theme Team Leaders. As previously reported, Co-PI Michael Rappé (University of Hawaii) leads former Co-PI James Cowen’s (deceased) research group, though not assuming an ExCom role.

ExCom maintains communication via weekly videoconference meetings, an annual face-to-face meeting, and ad hoc meetings at selected C-DEBI, national and international meetings, with participation by the Managing Director and as needed by members of the Administration; Research; Knowledge Transfer, Data Management and Integration; and Education, Outreach and Diversity Teams.

Administration

The administrative staff, led by Managing Director, Rosalynn Sylvan, is at USC, where they manage the Center’s day-to-day activities and all education, diversity, and outreach programs. They link to C-DEBI activities at the partner institutions and communicate with all participants worldwide. The Managing Director manages fiscal and grants administration and supervises the Administrative staff (including the Education and Diversity Directors, see Education and Outreach below). The Managing Director attends the weekly ExCom videoconference meeting and any other face-to-face ExCom meetings as the administrative liaison. The Data Manager, Matthew Janicak, is responsible for supporting the database infrastructure (see Data Management and Integration below) and development and maintenance of the website and other community communications. The Administrative Assistant, Nerissa Rivera, implements day-to-day activities of the center and is responsible for meeting coordination.

Research

C-DEBI major programs are led by ExCom (see above), while cross-cutting research themes were led by Theme Leaders. The Theme Team Leaders coordinated the four C-DEBI research themes: Activity, Extent of Life (i.e., Biogeography), Limits of Life, and Evolution and Survival and developed cross-cutting theme concepts to translate to major programs and proposal calls. In this function, they generated and promoted a conceptual framework for the scientific investigations within C-DEBI, effectively managing a ‘think tank’ for new research directions. Each Theme Team Leader also organized a theme-specific workshop on an approximately annual basis. Until their terms ended at the C-DEBI Annual Meeting (October 3-4, 2014), The Theme Team Leaders were: Beth Orcutt (Bigelow, Activity Theme), Andreas Teske (UNC, Extent of Life Theme), Thomas McCollom (Colorado U, Limits to Life Theme), and Julie Huber (MBL, Evolution and Survival Theme).

As detailed in the Research section II above, we are transitioning to three new research themes related to the renewal phase to encourage synthesis and integration across themes and sites. Five Senior Scientists were added to C-DEBI leadership to complement the ExCom expertise on these themes: Fluxes, Connectivity, and Energy (Theme 1); Activities, Communities, and Ecosystems (Theme 2); and Metabolism, Survival, and Adaptation (Theme 3). The Senior Scientists are Steven Finkel (Professor Bacterial Genetics and Molecular Biology at USC with expertise in mechanisms of long-term survival and evolution), John Heidelberg (Associate Professor of Marine and Environmental Biology at USC with expertise in metagenomics and metatranscriptomics), Beth Orcutt (Senior Research Scientist at Bigelow Laboratory for Ocean Sciences with expertise in geomicrobiology of subseafloor environments), Victoria Orphan (Professor of Microbial Ecology and Geobiology at the California Institute of Technology with expertise in the application of molecular techniques, microscopy, and stable isotope techniques to anaerobic microbial processes), and Alfred Spormann (Professor of Microbial Physiology and Biochemistry at Stanford University with expertise in metabolism, physiology, and metabolic ecology of anaerobic microorganisms).
Knowledge Transfer, Data Management and Integration

Knowledge Transfer is central to all of C-DEBI’s research, education, and outreach programs, and hence, it is the responsibility of all our senior personnel. The Knowledge Transfer Director, Geoff Wheat, coordinates and tracks the various knowledge transfer activities, with a special focus on dissemination of scientific and technical knowledge, increasing public awareness of the subseafloor biosphere, and promoting development and application of novel technologies through commercialization and entrepreneurial use of C-DEBI products.

The Data Management and Integration (DMI) team has the primary objective to make C-DEBI data and products accessible to the world via a data portal. The products include C-DEBI publications, data generated by C-DEBI projects, documentation of technological advances, and products for education and outreach. Renewal Senior Scientist, John Heidelberg leads the DMI effort, with support from personnel at USC (Data Manager Matthew Janicak and Bioinformatics Postdoctoral Benjamin Tully) and URI (Data Portal Lead Robert Pockalny). The DMI Director is also responsible for ensuring that C-DEBI participants have access to the Center’s computational resources and/or bioinformatics expertise, as well as making certain C-DEBI generated data are properly deposited in public archives and databases, including future EarthCube initiatives. The DMI team is responsible for supporting the database infrastructure and website.

Education, Outreach, and Diversity (EOD) Administration

The EOD team is based at USC and develops, implements, and coordinates EOD programs and activities. The Senior Advisor for EOD, Linda Duguay, provides oversight, leadership, and commitment to the integration of C-DEBI research with our EOD efforts at all levels. Duguay is also the Research Coordinator of the graduate student and postdoctoral fellowship program. The Education Director, Stephanie Schroeder, leads the professional development and mentoring efforts for undergraduate and graduate students, postdoctoral scholars, and K-12 teachers. The Education Director also serves as review chair of the small education and outreach grants proposals. The Diversity Director, Cynthia Joseph, leads programs to entrain members of underrepresented groups into STEM fields with a special focus on microbiology, geochemistry, and oceanography.

This year, we added Senior Advisor for EOD, Ann Close, to ExCom to integrate EOD with C-DEBI research. As of August, Ann Close was reassigned by the Dean of the College to the USC Wrigley Institute for Environmental Studies. We plan to continue to integrate EOD representation on ExCom as we develop our new personnel strategy.

External Advisory Board

The External Advisory Board provides annual assessments of the science, education, mentoring, management, and functioning of C-DEBI as a whole to the Directorship. The eight member committee of national and international leaders in both science and education includes Chair John Baross (U Washington), Estella Atekwana (Oklahoma State), Antje Boetius (MPI - U Bremen, Germany), Luis Cifuentes (Texas A&M), Joe Conner (Pasadena City College), Susan Humphris (WHOI), Anna-Louise Reysenbach (Portland State), and Henry Williams (Florida A&M). The EAB met at the 2014 C-DEBI Annual Meeting in a full day of meetings with various groups from C-DEBI leadership the day prior and convened during the meeting to continue discussion and work on recommendations. Overall, the EAB noted considerable improvement in the functioning and management of C-DEBI since the previous year. The EAB reports to the directorship in confidence, and their recommendations are communicated confidentially. The chair of the EAB will present their assessment at the Site Visit.

Ethics Panel

The Ethics Panel advises ExCom on any issue pertaining to ethics, including concerns regarding administration, funding, and scientific conduct. This Panel handles all C-DEBI ethics complaints and convenes (electronically or in person) on an ‘as needed’ basis or on request of ExCom. The panel also makes recommendations to ExCom with respect to ethics training programs for C-DEBI members. The
Ethics Panel consists of Chair Karen Lloyd (Assistant Professor at U Tennessee), Frederick Colwell (Professor at Oregon State), Andrew Fisher (ExCom), Sharon Cooper (Associate Education Director at Consortium for Ocean Leadership), and William Orsi (Postdoctoral Researcher at WHOI), representing several groups within C-DEBI. To date, the committee has not received any ethical complaints. See more at our Ethics Policies webpage.

External Evaluator
The External Evaluator, Beth Rabin, assesses and evaluates the effectiveness of C-DEBI management, research (specifically the drilling expeditions), and education, outreach, and diversity programs and provides thorough, rigorous, independent, and results-based assessments to ExCom.

Education & Outreach Steering Committee
The Education & Outreach Steering Committee serves in an advisory role to the EOD Administration and also helps to review the small education and outreach grant proposals. The committee consists of current or previous STC Education and Diversity Directors Sharnnia Artis (UC Berkeley), Diana Dalbotten (U Minnesota), Vanessa Green (Oregon Health & Science U), and Keith Oden (Georgia Tech).

2. Management and Communications Systems

C-DEBI is a distributed center, with members and participants around the world. The STC and its participants have ample experience in long-distance collaboration and communication. There are weekly administrative and ExCom meetings via videoconferencing. We have a biweekly newsletter (sent to 900+ e-mail addresses), a regularly updated website, and C-DEBI also has a presence on social media, including Facebook (cdebi) and Twitter (@deepbiosphere). C-DEBI’s annual meeting includes leadership and advisory groups, graduate and postdoctoral fellows, and invited guests. We also organize several targeted workshops annually and encourage members (especially postdoctoral scholars and early career scientists) to organize sessions at national and international meetings. Coordination of these communication activities is under the purview of the Administrative team.

Our website represents, in may ways, the face of C-DEBI, serving the general public as well as the scientists and educators looking for specific resources. We are currently working on a major redesign of the landing page to better convey the excitement of C-DEBI science, education, and outreach. Our target date for the rollout of the new landing page is the 2015 site visit. As part of this, we have produced two versions of a C-DEBI overview video, with short interviews, clips of field and lab research, education activities, and more. The website will also integrate resources available through the data portal (see Data Management and Integration in section IV above). We have also improved our newsletter, and have worked with the press offices at USC and partner institutions to prepare better press releases and other media elements that can help to elevate the impact of C-DEBI projects and discoveries.

3. Performance with Respect to the Strategic Implementation Plan

Our leadership and management goal is to envision and enable the Center’s mission through inclusive and transparent decision-making; inspire Center members; and facilitate collaborative effort and guide all participants in the center via a cross-disciplinary and multi-institutional ethics program to instruct them on ethical and responsible conduct of scientific research.

A fundamental challenge for C-DEBI leadership is to maintain trust and support among a diverse and interdisciplinary community of scientists, educators, and technologists. Maintaining confidence in STC leadership, throughout the existence of the Center, is essential if busy STC participants are to retain a willingness to allocate some of their limited time for advisory, review, and collaborative activities. STC
leaders will also need to assure that there are robust opportunities for inter-institutional and cross-disciplinary exchanges and training, and help to secure external resources in support of ongoing and future STC activities. In addition, the Center will maintain a rigorous ethics training system for all C-DEBI participants and an Ethics Panel overseeing policies and procedures. Finally, STC leadership needs to remain focused on the critical goal that motivated formation of C-DEBI in the first place: creating a vibrant, innovative, and focused community, who will work together to achieve what cannot be accomplished by individuals working alone, to transform the nature of deep biosphere research.

**Target 1:** The decision-making process is defined, transparent and effective leading to a high degree of confidence, ownership, and engagement by STC participants in the Center.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hold weekly administration meetings as well as weekly PI (ExCom) meetings and an annual ExCom face-to-face retreat to enable clear and effective management of the Center</td>
<td>Met</td>
</tr>
<tr>
<td>Survey the community every 1-2 years to establish effectiveness of leadership teams, decision making, and Center engagement with 70% of respondents rating leadership as being “clear/effective” or “very clear/effective”</td>
<td>Met</td>
</tr>
<tr>
<td>Invite the evaluation of Center research, education, diversity, and knowledge transfer management annually by the External Advisory Board (typically in conjunction with the C-DEBI annual meeting) for feedback and suggestions to the Director to improve the integration of C-DEBI programs and activities</td>
<td>Met</td>
</tr>
<tr>
<td>Update the C-DEBI Operations Manual annually to elucidate the functions of key individuals and groups and main research, education, outreach, and administration activities, programs, operations and procedures and post on the website with the Annual Report and Strategic Implementation Plan</td>
<td>Met</td>
</tr>
</tbody>
</table>

**Target 2:** Communication is effective in facilitating the exchange of science, education of students, and promotion of other C-DEBI activities and opportunities.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regularly update the comprehensive website at <a href="http://www.darkenergybiosphere.org">www.darkenergybiosphere.org</a> with research and education portals and resources</td>
<td>Met</td>
</tr>
<tr>
<td>Distribute biweekly newsletters to C-DEBI community (participants and affiliates) to highlight recent and upcoming C-DEBI research and education programs and events and other relevant/partner activities and opportunities</td>
<td>Met</td>
</tr>
<tr>
<td>Continue to improve the private login site for internal documents and community reporting</td>
<td>Met</td>
</tr>
<tr>
<td>Solicit 3 nominations for the next season of the videoconferenced Networked Speaker seminar series to present early career scientist research to the C-DEBI community</td>
<td>Met</td>
</tr>
</tbody>
</table>
Maintain protocol/procedure for issuance and usage of C-DEBI contributed publication numbers and of logo and branding information | Met

**Target 3:** STC participants are engaged in cross-Center training and collaboration.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organize 5-7 C-DEBI-specific opportunities for collaboration and training and entrain new membership (e.g., Center-wide All Hands Meetings, Theme Team Workshops, and Exchange Grants)</td>
<td>Met</td>
</tr>
<tr>
<td>Support 4-6 research and professional development opportunities specifically for graduate students and postdoctorals (e.g., mini-workshops at Annual Meetings, professional development webinars, and fellowships and networking activities in Research and Education sections above)</td>
<td>Met</td>
</tr>
</tbody>
</table>

**Target 4:** Community commitment to an environment promoting high ethical standards in the conduct of research is maintained.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Require 100% of participants complete ethics training within these standards</td>
<td>Met</td>
</tr>
<tr>
<td>Ethics Panel composed of Research, Education, ExCom and Postdoctoral representatives resolves complaints regarding C-DEBI administration, funding and scientific conduct in a timely manner (within 6 months of being presented to C-DEBI)</td>
<td>Met</td>
</tr>
</tbody>
</table>

**Target 5:** Strategies, tools, and resources are developed for sustainability of C-DEBI activities.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Status/Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secure $2M in aggregate (beyond initial STC funding) in support of C-DEBI activities</td>
<td>Met</td>
</tr>
</tbody>
</table>

4. Plans for the Next Reporting Period

To further enhance C-DEBI’s culture of collaboration and cross-disciplinary thinking, we will continue to develop cyber-infrastructure for our website enabling public access and data sharing among the C-DEBI research community. The architecture for our online communities for collaboration and learning for has two principal objectives: 1) to support the connection among scientists and others in the C-DEBI project research community and 2) to foster the connections between C-DEBI scientists and educators.
VIII. CENTER-WIDE OUTPUTS AND ISSUES

1. Center Publications

In the current reporting period, the C-DEBI community published 39 publications including 38 contributed publications (Appendix I). Graduate and postdoctoral authors are highlighted and contributing C-DEBI funding, Major Program association and Theme association are included per publication.

2. Conference Presentations and Other

Center participants presented over 160 oral and poster presentations at venues including the 2014 International Symposium on Subsurface Microbiology, Goldschmidt 2014, and 2014 AGU Fall Meeting (Appendix I).

3. Honors, Awards and Grants

C-DEBI participants reported receiving 38 (with another 12 pending) honors, awards and grants during the reporting year related to their C-DEBI funding (Appendix I).

4. Placement of Graduated Students and Postdoctorals

Fifteen C-DEBI undergraduate, graduate students, postdoctorals and early-career scientists obtained degrees or placement during the current reporting year (Appendix I). C-DEBI funding contributing to degrees or placement is identified.

5. Outputs of Knowledge Transfer Activities

The C-DEBI community developed 10 technologies (6 with potential industry uses) in the current year including platforms, sensors, laboratory techniques and software, as well as 1 startup company (Appendix I). One commercial product, an interactive eBook, is currently in development for release on iTunes when completed. See also the Knowledge Transfer section IV above.

6. All Participants

Of the 343 individuals involved with the Center, 198 are “participants”, defined by the NSF STC Reporting Requirements as individuals who have spent over 160 hours on Center activities, while 145 are “affiliates”, reported as spending under 160 hours. Affiliates are included where they were reported as personnel on a C-DEBI grant or other budgeted item, attended a C-DEBI event, or have a titular role in the Center. Sources of Center support and known, subseafloor-related, event attendance are included per participant to provide further differentiation of engagement level. See Appendix I for details.
7. Institutional Partners

C-DEBI includes participation by 149 institutions with “partner types” defined as research, education, knowledge transfer, diversity, or other per the NSF STC Reporting Requirements. Institutions are assigned these types based on the activities of its participants as follows: if an institution has a graduate student or postdoctoral participant, it is assigned the types of “education” and “research”; if it has a research grantee or other funded recipient doing Center research, it is assigned a type of “research”; if it has a participant involved in general outreach, it is assigned a type of “education”; if involved in education or outreach targeting diverse groups, it is assigned types of “education” and “diversity”; if it has a participant working on new tools, software or methods, it is assigned a type of “knowledge transfer”; finally if it has a participant from an advisory body, such as the EAB, it is assigned all four types. Whether the institution has “participated” less or more than 160 hours is likewise determined by its affiliated participants. See Appendix I for details. See also the External Partnerships section V above.

8. Summary Table for Internal NSF Reporting Purposes

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of participating institutions (all academic institutions that participate in activities at the Center)</td>
<td>77</td>
</tr>
<tr>
<td>Number of institutional partners (total number of non-academic participants, including industry, states, and other federal agencies, at the Center)</td>
<td>72</td>
</tr>
<tr>
<td>Total leveraged support (funding for the Center from all sources other than NSF-STC)</td>
<td>$366,825</td>
</tr>
<tr>
<td>Number of participants excluding affiliates (total number of people who utilize center facilities; not just persons directly supported by NSF)</td>
<td>198</td>
</tr>
</tbody>
</table>

9. Media Publicity

Twenty-four media publicity items have been identified, including press releases, news articles, videos, a social media campaign from Al Jazeera America, and film festival prizes for the North Pond documentary (Appendix I).

10. Distributable Media

Our current brochure provides an overview of the deep biosphere, C-DEBI research programs and themes, C-DEBI education and outreach programs, and how to get involved.
IX. INDIRECT/OTHER IMPACTS

1. International Activities and Other Outputs, Impacts, or Influences

By virtue of being a distributed center, C-DEBI regularly engages the international community in the majority of its activities with individual and organizational partnerships as described throughout this report. No other outputs, impacts, or influences have not been captured elsewhere in this report.