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# I. GENERAL INFORMATION

## 1. Center General Information

|  |  |
| --- | --- |
| **Date Submitted** | 12/31/2015 |
| **Reporting Period** | 1/1/2015 - 12/31/2015 |
| **Center** | Center for Dark Energy Biosphere Investigations |
| **Center Director** | Jan P. Amend |
| **Lead University** | University of Southern California |
| **Co-Principal Investigator** | Steven L. D’Hondt, University of Rhode Island |
| **Co-Principal Investigator** | Andrew T. Fisher, University of California Santa Cruz |
| **Co-Principal Investigator** | Julie A. Huber, Marine Biological Laboratory |
| **Co-Principal Investigator** | C. Geoffrey Wheat, University of Alaska Fairbanks |
| **Co-Principal Investigator** | Michael S. Rappé, University of Hawai’i at Manoa |

## 2. Changes in Faculty

None.

## 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 the four major programs and other projects. It should be noted that no new expeditions visited JdF, SPG, or NP during this reporting period, but submersible operations were carried out at DO in late 2014 (briefly noted in last year’s report). At JdF, work continued in 2015 on sample and data analysis as well as on numerical modeling. Nine manuscripts were completed with new findings in hydrogeology, biogeochemistry, and microbial ecology. For example, results from the first 3-D simulations of ridge-flank hydrothermal fluid circulation were published, as were the first data on cross-hole tracer experiments in the igneous crust. In addition, C-DEBI graduate and postdoctoral fellows led several studies on organic matter composition, microbial communities, and viruses in JdF basement fluid and the overlying sediments. Lastly, several synthesis studies were completed that compared and contrasted JdF results with data from other settings.

At SPG, the output of scientific findings also continued in 2015 with numerous publications. For example, it was shown that microbial cells and aerobic respiration persist throughout the entire sedimentary sequence at SPG, that radiolytic H2 production can be important in marine sediments and the underlying basaltic aquifer, and that subseafloor sediment microbial communities may be seeded from the overlying ocean. Technical advances of note include improved quantification, in part through new algorithms, of H2 yields by alpha radiation.

Research at NP in 2015 continued to focus on sediment, rock, and fluid samples from the 2011 drilling expedition and the 2012 and 2014 ROV programs, as well as the interpretation of previously obtained data. For example, C-DEBI researchers determined the extent and magnitude of microbial N and P cycling in sediments, and several studies provided phylogenetic and functional characterization of rock-hosted microbial communities. In addition, 2015 saw the first publication on the use of a new downhole imaging tool (DEBI-t) designed to optically detect microbial cells and spores attached to surfaces. Technical accomplishments also included the completed, detailed technical drawings of new CORK systems (CORK-lite), designed for future use at legacy holes that are distributed across the floor of the world’s ocean.

DO was visited by the R/V Atlantis in December 2014 (AT26-24). Ten Alvin dives were completed on which 13 gravity cores were collected, 1 CTD hydrocast was conducted, and 4 bathymetric surveys were completed. Much of the focus for these dives was on the collection and sensing of pristine venting fluids for geochemical and microbial analysis and the recovery of sensors, samplers, and experiments to constrain biogeochemical processes and rates of activity. A few manuscripts have already been prepared with several more in the pipeline. Key findings include the presence of dissolved oxygen in the spring fluids, diverse microbial communities (based on 16S rRNA gene sequences) dominated by Proteobacteria and Thaumarchaeota, and simulations of regional, outcrop-to-outcrop crustal hydrology. Several technical accomplishments were recorded, including of particular significance the development of hydrologic models for elucidating subsurface flow patterns and magnitude.

In the transition to Phase 2, C-DEBI assumed leadership roles in several other field-based, laboratory, and modeling studies as well. The new field expeditions include, among others, the Atlantis Massif, where the primary scientific objective is to investigate the variation and connectivity of microbial life in a high pH, serpentinizing subsurface environment; the Bay of Bengal to elucidate microbially mediated nutrient transformations in subseafloor sediments; the Pescadero Basin, where the focus is on a carbonate-hosted vent field; Axial Seamount on the Juan de Fuca Ridge to continue geophysical, chemical, and biological time-series at this active submarine volcano; and the Baltic Sea Basin to survey (active) microbial communities through single-cell genomics, metagenomics, transcriptomics, and cultivations. Other projects were supported, in large part by our grants and fellowship program, which counted 47 active projects in 2015. While some of these awards support research related to the major programs and other field projects, others support experimental, analytical, and numerical studies relevant to C-DEBI. Of particular note was a special call for projects that emphasized the 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.

C-DEBI’s mailing list counts approximately 1000 individuals in nearly 30 countries. Of these, over 250 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 18 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 65 individuals received funding this year through the C-DEBI grants and fellowships program.

C-DEBI’s education, outreach, and diversity programs focused predominantly on community college students and instructors, underrepresented undergraduate students, and graduate and post-doctoral researchers. Our Community College Research Internship for Scientific Engagement, a non-residential REU-style program, was held for the 3rd year; this year, students joined labs at UCSC and MBL, as USC was not available during the summer because of the Special Olympics. In 2015, we also partnered with new C-DEBI Senior Scientist Steve Finkel to expand his established undergraduate research internship program at USC that targets underrepresented minorities the Genomics and Geology Undergraduate Research Experience. In addition, we again joined forces with the Agouron Institute to lead the International GeoBiology summer course, one of the premier training opportunities for graduate students. 2015 also saw the 5th annual installment of the Global Environmental Microbiology course, a field-based, hands-on 4-week program targeting underrepresented early undergraduate students. Lastly, as part of our recent REU award, we started to prepare an ambitious research agenda—to fully characterize one or more novel marine subsurface microbial isolates.

C-DEBI was renewed in 2015, with 5-year Phase 2 starting on October 1. In response to our experiences from the first phase, input from the larger subseafloor biosphere community, and annual site visit reports, several significant changes were implemented. The leadership team was expanded by five Senior Scientists (Steve Finkel and John Heidelberg at USC, Beth Orcutt at Bigelow, Victoria Orphan at Caltech, Alfred Spormann at Stanford), strengthening our focus on microbiology. The research agenda is transitioning from predominantly discovery-based field programs to a balanced portfolio of field, laboratory, and modeling studies, the combination of which will permit broader data integration and synthesis. Of particular note is our much stronger focus on data management and integration, a complex undertaking led by new Senior Scientist Heidelberg. Lastly, we have taken steps to more closely couple our education, outreach, and diversity programs with our focused research activities; this is aided by the addition of our Education Director to C-DEBI’s Executive Committee.

# 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.e (Other Field 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.

During the first 5 years of C-DEBI (Phase 1), 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.

For the next 5 years (Phase 2), we initiated a transition in our research framework. Discovery science, where research activities are dominated by field measurements, instrument development and deployment, and sample analysis, will be balanced with hypothesis testing, data integration, laboratory experimentation, and ecosystem modeling. The strategic research transition led to a modification of the overarching research themes and associated objectives; these will maintain highly multidisciplinary and interdisciplinary approaches, with its greatest emphasis on microbial ecology. In Phase 2, the research themes are:

***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 (UAF) will be Steven Finkel (Professor of 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 in 2015 and mention noteworthy problems (if any) and our solutions to those problems. The first five subsections (2.a-e) cover the major programs at Juan de Fuca Ridge Flank, South Pacific Gyre, North Pond, and Dorado Outcrop, as well as other field projects. We provide a brief background on each and describe the key operational, scientific, and technical accomplishments. The last subsection (2.f) briefly highlights other research projects, those without a major field component, including projects 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) major program is exploring the nature of linked hydrogeologic, geochemical, and microbiological conditions and processes in a region that is the best understood example of ridge-flank hydrothermal circulation on the planet. In this setting, a volcanic crustal aquifer contains highly altered (suboxic to anoxic), warm (64 °C) hydrothermal fluids that are isolated from the overlying ocean in most locations by hundreds of meters of hemipelagic sediment and turbidites. Projects using data and field samples from this region have included two IODP expeditions (301 and 327); long-term borehole observatories (CORKs) used for testing, monitoring and sampling; and numerous non-drilling oceanographic expeditions using oceanographic ships and submersibles/ROVs, laboratory studies using materials and associated microbial cultures, and theoretical and computational experiments. Tools and methods developed for the JdF program have been adapted and applied at other sites, including other C-DEBI major program locations. The JdF major program has contributed to training of numerous graduate and undergraduate students and other junior researchers, including those who add diversity to the STEM pipeline; has linked researchers and students from across the US and around the world, who work on common technical and scientific goals; and has comprised the basis for several successful education and outreach programs to the K-12 community and the public at large.

More specifically, the JdF major program has explored these and related questions:

* What are the rates, directions, and distributions of fluid and coupled energy, solute, and microbial processes within the volcanic crustal aquifer?
* How do microbial populations in the volcanic crust differ from location to location, and from those found in the overlying ocean and sediments?
* How do microbial processes contribute to rock and fluid alteration?

Answering these and related questions will help to achieve goals important to Phase 2 of C-DEBI, within all three of the new program themes (*Connectivity and Fluxes*, *Activities and Communities*, *Metabolism and Survival*). As discussed in several of the publications and presentations highlighted below, the JdF major program emphasizes a ridge-flank hydrothermal system that represents an important end-member in terms of crustal temperature, redox state, and through-put of fluids (and associated solutes, inoculum, etc). Results from this area are especially important in comparison to results derived from the NP and DO major programs. The latter is a system operating at much cooler and more oxic conditions, which may be characteristic of a large fraction of young and well-ventilated volcanic crust, whereas JdF is more typical in many ways of older sites where there is much more limited exposure of permeable basement rocks to the overlying ocean. The JdF major program is also distinct for being the first at which controlled, cross-hole experiments have been completed, including the first tracer-injection experiment in the ocean crust. In addition, the JdF studies have produced the longest time-series records of subseafloor conditions, including high-quality and large-volume subseafloor samples collected from multiple boreholes and depths.

**Summary of Significant Accomplishments During Review Period**

 During this reporting period, there were no expedition-based studies and instead, work in 2015 focused mainly on sample and data analysis, analytical studies, and numerical modeling. However, the JdF major program has continued to produce high-profile results, with 6 peer-reviewed publications in print or in press, 3 manuscripts in review, 23 oral and poster presentations at national and international meetings, and 1 Ph.D. thesis completed during this reporting period. In this section, we highlight selected research results, with an emphasis on peer-reviewed publications.

 Results of the first three-dimensional simulations of fluid circulation within a ridge-flank hydrothermal system were published in *Nature Communications* (Winslow and Fisher, 2015), and a more detailed study is in reviewat *J. Geophys. Research* (Winslow et al., 2015). Field studies and analytical models have shown that there is large-scale fluid flow in the volcanic ocean crust in the JdF region, including vigorous local convection and circulation between basement outcrops separated by ~50 km. Key field observations that help to constrain new simulations include a modest range of flow rates between recharging and discharging outcrops (5-20 kg/s), secondary convection adjacent to the recharging outcrop, crustal permeability determinations made in boreholes, and the lack of a regional seafloor heat flux anomaly as a consequence of advective heat loss from the crust. New models demonstrate that sustaining flow between outcrops that penetrate less-permeable sediment depends on there being a contrast in transmittance (the product of outcrop permeability and the area of outcrop exposure) between recharging and discharging sites, with discharge being favored through less-transmissive outcrops. Many simulations include local discharge through outcrops at the recharge end of an outcrop-to-outcrop system. Both of these characteristics are observed at the JdF field site. In addition, smaller discharging outcrops sustain higher flow rates than larger outcrops, which may help to explain how so much lithospheric heat is extracted globally by this process. Three-dimensional simulations are most consistent with field observations when models use a narrow range of crustal permeability, about 0.1 to 1 Darcies, and the crustal aquifer is ≤300 m thick, values consistent with borehole observations. Simulations also show that fluid flow rates and crustal cooling efficiencies are an order of magnitude greater in three-dimensional simulations than in two-dimensional simulations using equivalent properties. Simulations including discharge from an additional outcrop to the north of the field site can also replicate field observations, but tend to increase the overall rate of recharge and reduce the flow rate at the primary discharge site. These simulations will form the basis for future modeling studies during C-DEBI Phase 2, with new models incorporating more complex patterns of heterogeneity in crustal properties and associated variations in reactive transport.

 A study based on the first cross-hole tracer experiment in the volcanic ocean crust was completed and submitted during the 2015 review period (Neira et al., 2015). This study tracked the injection and transport of a dissolved gas tracer (sulfur hexafluoride, SF6), using an array of CORKs instrumented with autonomous fluid samplers. All of the fluids used for this study were collected using wellhead samplers, with tubes and fittings that connected the samplers to crustal intervals hundreds of meters below the seafloor. During the first three years after tracer injection, SF6 was transported both north and south through the crustal aquifer, with an observed tracer transport rate of ~2 m/day. This is orders of magnitude faster than inferred from either thermal and chemical observations and/or the results of coupled fluid-heat flow simulations (described above). Taken together, these results suggest that the effective porosity of the upper volcanic crust, the volumetric fraction of rock through which most lateral fluid flow occurs, is <<1%, with most of the fluid flowing rapidly along a few well-connected channels, and the rest of the crust being dominated by diffusive and reactive processes. This finding is consistent with the heterogeneous (layered, faulted, and/or fractured) nature of volcanic upper ocean crust, and will require careful representation of physical and geochemical characteristics in future reactive transport models (e.g., relatively low specific surface area for reaction, limited interaction between microbes and flowing fluids). Additional work is underway to analyze tracer concentrations in downhole samples recovered in Summer 2014 from four CORK systems (deJong et al., 2015). These samples provide critical information on tracer transport during the four years following tracer injection, including a time period that is not represented in the seafloor samples analyzed to date, prior to wellhead instrumentation of new CORKs installed on IODP Expedition 327.

 Lin et al. (2015b) completed a study of dissolved and particulate organic matter in sediments overlying basement that is close to the Grizzly Bare outcrop, the primary site of hydrothermal recharge for this ridge flank. They found that sedimentary DOC increased from 0.25 mM at 1 m below the seawater sediment interface to a maximum of 0.86 mM at mid-depth (8–11 meters below seafloor [mbsf]), before subsequently decreasing to a minimum of 0.10 mM at the sediment/basement interface. Thus, the oceanic basement appears to be a net sink for sedimentary DOC in this location. This finding is complementary to work by Orcutt et al. (2015) and Lin et al. (2015a) indicating that microbial processes in the volcanic upper crust include significant oxygen removal. Sedimentary DOC and alkalinity profiles were similar, and inversely mirror those of sulfate, suggesting that the buildup of DOC in pore water in the middle of the column is related to remineralization of sedimentary POC.

 Lin et al. (2015a) evaluated basement fluid samples collected from three CORKs in the JdF region, finding dissolved free amino acids (1–13 nM) and dissolved hydrolyzable amino acids (43–89 nM) in the volcanic upper crustal aquifer. The amino acid concentrations in the ridge-flank basement fluids are relatively low, but similar to those found in deep seawater. Potential sources of amino acids in the basement fluids include: amino acids in deep seawater that recharges the crustal hydrothermal system, in situ amino acid production, and diffusional input from overlying sediments. Thermodynamic modeling shows that amino acid synthesis in the basement can be sustained by energy supplied from inorganic substrates via chemolithotrophic metabolisms. Furthermore, an analysis of amino acid concentrations and compositions in basement fluids support the hypothesis that there is ongoing heterotrophic activity in this system. Similarly, the enrichment of acidic amino acids and depletion of hydrophobic ones relative to sedimentary particulate organic matter suggests that surface sorption and desorption alter amino acids in the basaltic basement. In summary, although the oceanic basement aquifer is a net sink for deep seawater DOC, similar amino acid concentrations in basement aquifer and deep seawater suggest that DOC is preferentially removed in the basement over dissolved amino acids. This study also suggests that organic carbon cycling occurs in the oceanic basaltic basement, where an active subsurface biosphere is likely responsible for amino acid synthesis and degradation.

 A new study by Jungbluth et al. (2015, *in press*) represents a major advance in understanding how microbial communities in the upper ocean crust relate to those seen in overlying sediments and the ocean. In this study, the analysis of 1.7 million small subunit ribosomal RNA genes amplified and sequenced from marine sediment, bottom seawater, and basalt-hosted deep subseafloor fluids that span multiple years and locations on the Juan de Fuca Ridge flank was used to quantitatively delineate a subseafloor microbiome comprised of distinct *Bacteria* and *Archaea*. Hot, anoxic crustal fluids accessed with CORKs contained abundant bacterial lineages of phylogenetically unique *Nitrospirae*, *Aminicenantes*, *Calescamantes*, and *Chloroflexi*. While less abundant, the domain *Archaea* was dominated by unique, uncultivated archaeal lineages of marine benthic group E, the thermal hot spring crenarchaeotal group, the Miscellaneous Crenarchaeotal Group, and relatives of cultivated, sulfate-reducing *Archaeoglobi*. Consistent with recent geochemical measurements and bioenergetic predictions, potential importance of methane cycling and sulfate reduction were imprinted within the basalt-hosted deep subseafloor crustal fluid microbial community. This unique window of access to the deep ocean subsurface basement reveals a microbial landscape that exhibits previously undetected spatial heterogeneity.

 Ongoing studies have also explored the nature of viruses in the volcanic ocean crust (Nigro et al., 2015a, 2015b, Steward et al., 2015). While viruses undoubtedly affect the ecology of microbial communities inhabiting this high-pressure, extreme environment, their significance remains mostly unknown. Recent improvements in sampling infrastructure have allowed the processing of large volumes of crustal fluids (thousands of liters) retrieved from JdF CORKs. Analysis of TEM images revealed distinct viral morphologies (rod and spindle-shaped) that resemble the morphologies of viral families infecting archaea. There are very few, if any, direct observations of these viral morphologies in marine samples, although they have been observed in enrichment cultures and their signature genes detected in metagenomic studies from hydrothermal vents and marine sediments. Analysis of metagenomes from the JdF crustal fluids revealed sequences with homology to archaeal viruses from the rudiviridae, bicaudaviridae and fuselloviridae. Prokaryotic communities in fluids percolating through the basaltic basement rock of the JdF are distinct from those inhabiting the overlying sediments and seawater. Similarly, our data support the idea that the viral assemblage in these fluids is distinct from viral assemblages in other marine and terrestrial aquatic environments. This study also suggest that viruses contribute to the mortality of deep subsurface prokaryotes through cell lysis, and viruses may alter the genetic potential of their hosts through the processes of lysogenic conversion and horizontal gene transfer.

 These biogeochemical and microbial studies could not have been completed without large volumes of pristine fluids from deep below the seafloor; *this technical capability did not exist prior to C-DEBI Phase 1*. Developing and applying a series of linked tools that permit access to samples of this kind (clean CORK observatory sealing and sampling systems, long-term pumps with inline filters, autonomous instrumentation control, etc.) comprises a significant technical achievement. The studies described above, and additional work documented in the bibliography, shows the way forward into Phase 2 of C-DEBI. Thermal, tracer, and modeling studies help to address issues of importance to the *Fluxes and Connectivity* theme, and environmental, laboratory and theoretical studies are helping to resolve questions related to the microbial *Activity and Communities* theme and hypotheses involving the *Metabolism and Survival* theme.The nature of links between the JdF major program and Phase 2 research themes is especially apparent in synthesis studies, which have compared and contrasted JdF results to those achieved with samples and data from other settings (e.g., Lever et al., 2015; Orcutt et al., 2015).

**Summary of Problems and how they were Addressed During Review Period**

There were no major issues during the reporting period.

► See more at the [Juan de Fuca Ridge Major Program webpage](http://www.darkenergybiosphere.org/research/juandefuca.html)

► See References Cited in [[Appendix A](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-A-References-Cited.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-A-References-Cited.pdf)

► See related C-DEBI Contributed Publications in [[Appendix L](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-L-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)

**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 activity in this program continues to focus 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?

Answers to these questions have addressed the four original themes in Phase 1 and continue to provide valuable insight to the objectives in the Phase 2 research themes. 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 2015, we published our discovery that microbial cells and organic-fueled aerobic respiration persist throughout the entire SPG sediment sequence (D’Hondt et al., 2015). 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). In collaboration with approximately 30 other researchers, we are now studying this extremely electron-donor-limited aerobic ecosystem and its inhabitants in both the South Pacific Gyre and the North Atlantic Gyre. Recent results from these collaborative projects are the focus of both oral and poster sessions convened by graduate students Emily Estes, Chloe Anderson, Ann Dunlea and Claire McKinley at the 2015 Fall AGU Meeting (PP41C and PP43A: Geochemistry and Microbiology of Oxic and Suboxic Deep-Sea Pelagic Sediments I and II).

The SPG program had several additional scientific accomplishments in 2015. These include (i) experimental demonstration that H2 production per unit of radiation is amplified by up to a factor of 15 in marine sediment, with particularly strong production in abyssal clay and silicious ooze (Sauvage et al., 2015), (ii) 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., 2015), (iii) demonstration that human-associated fungi are ubiquitous in published reports of subseafloor sedimentary eukaryotes (Fulfer et al., 2015), and (iv) quantification of radiolytic H2 production in fractures of the SPG basaltic aquifer (Dzaugis et al., in review).

The first result indicates that (i) radiolytic H2 may be an especially important electron donor for microbes in organic-poor abyssal sediment, and (ii) zeolite should be used with caution (or not at all) in treatment of major radioactive spills (such as the Fukushima disaster). The second result implies that subseafloor sedimentary communities are seeded from the overlying ocean during initial sediment deposition. The third result indicates that either human-associated fungi are widespread members of subseafloor sedimentary communities or sample and analytical contamination is so pervasive that the existence of a deep subseafloor eukaryotic community remains uncertain. The fourth result demonstrates that (i) radiolytic H2 may be a more abundant electron donor than reduced iron in ancient (>10 Ma) subseafloor basalt, and (ii) radiolytic H2 production in a one-square-cm column of fracture water may support as many as 50 cells (depending on fracture thickness and basalt radioactivity)

*Technical Accomplishments*

The primary technical advances of the SPG program in 2015 were (i) our experimental quantification of hydrogen yields by alpha radiation in seawater and in natural marine sediment types (Sauvage et al., 2014), and (ii) publication of a robust algorithm for calculating radiolytic H2 production rates at solid/fluid interfaces (e.g., in basaltic fractures and surrounding solid nuclear waste in fluid repositories) (Dzaugis et al., 2015). The first advance provides the first quantification of H2 yields by alpha radiation in marine sediment (and perhaps in any natural geological material). The second advance provides the first robust and accurate algorithm for calculating radiolytic H2 production in hard-rock aquifers.

**Summary of Problems and how they were Addressed During Review Period**

Our primary technical challenges during this reporting period were development of appropriate techniques for quantitative experimental alpha irradiation and quantitative experimental alpha irradiation of natural wet sediment samples. We solved these problems and completed key alpha irradiation experiments (Sauvage et al., 2015).

► See more at the [South Pacific Gyre Major Program webpage](http://www.darkenergybiosphere.org/research/southpacgyre.html)

► See References Cited in [[[Appendix A](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-A-References-Cited.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-A-References-Cited.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-A-References-Cited.pdf)

► See related C-DEBI Contributed Publications in [[Appendix L](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-L-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-L-Center-wide-Outputs.xlsx)

**c. Major Program: North Pond**

**Led by:** Geoff Wheat, University of Alaska Fairbanks

**Background**

About one-third of the seafloor is underlain by oceanic crust that was formed at slow spreading ridges, resulting in seafloor morphology with many ridges and valleys (“mountain ranges”) that are roughly parallel to the spreading center. With age, the valleys fill with sediment, but exposed basalt is commonplace, allowing seawater to ventilate and cool the crust. The North Pond (NP) project was envisioned to investigate the origin, nature, and activity of microbial communities within basaltic basement below an isolated sediment "pond". NP, which is located on the western flank of the Mid-Atlantic Ridge at 22°45'N and 46°05'W and overlies 8Ma-old crust, was chosen in part because the site has been explored for decades. These exploratory studies have provided a geologic and hydrologic context for microbial studies. Most recently, subseafloor observatories (CORKs) were installed at NP during IODP Expedition 336 (Sept.-Nov. 2011) to collect and monitor active, low temperature, oxygenated fluids that advect vigorously through basaltic basement and to take the first step in conducting manipulative experiments within this natural setting. The three guiding questions for research at NP are:

* 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, and many more detailed ones, a team of international researchers undertook a site survey expedition prior to IODP Exp. 336, during which material was recovered (sediment and crustal rocks) and three borehole observatories were installed (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. Much of the cost for this fieldwork was supported by our German colleagues, the IODP, and the Gordon and Betty Moore Foundation. Results completed this year from samples and data recovered during these four expeditions continue to shed light on all four Phase 1 C-DEBI themes. In addition, ongoing and planned research fit within the context of the three Phase 2 themes.

**Summary of Significant Accomplishments During Review Period**

*Operational Accomplishments*

Among the biggest challenges for conducting research at NP are collecting samples, making measurements, and conducting active and passive experiments. Carrying out experiments at NP requires a 5-day transit from any port and working at a depth of 4400 m; the latter limits the instrumentation amenable to conducting the desired operations. During this review period, an NSF Marine Geology and Geophysics grant was awarded to use a UNOLS ship and the ROV Jason II to return to NP. This represents the first UNOLS ship to this site in over a decade. Although the focus for this expedition was presented with geochemical- and hydrology-pointed questions, our proposed activities to collect discrete samples and recover data and downhole samplers and experiments serve more focused microbial-related research. The integration of this work will help address the microbially-focused questions posed above and defined in the C-DEBI renewal proposal. Furthermore, by defining microbial processes within this geologic/hydrologic context we will be able to apply results from NP to a broader crustal context and shape future directions of study on slow spreading crust.

*Scientific Accomplishments*

Research in 2015 continued to focus on analyses of samples from the 2011 drilling expedition and the 2012 and 2014 ROV programs. Accomplishments span a range of disciplines, using data from sediment, basement rock, and fluid samples, and technical advances that have been developed by C-DEBI investigators. Key results from a selection of published articles and manuscripts in review are summarized here.

Research on NP sediments by C-DEBI Postdoctoral Fellow C. Buchwald and her advisor S. Wankel determined the extent and magnitude of microbial nitrate production (via nitrification) and consumption (via denitrification) in sediment pore waters from IODP Exp. 336, reaching the conclusion that autotrophy (e.g., nitrification, nitrogen fixation) is an important mechanism for organic mater production, supplementing heterotrophy of deposited organic matter from the overlying euphotic zone (Wankel et al. 2015). Also, C-DEBI Graduate Student Fellow D. Defforey and her advisor A. Paytan determined the different phases of phosphate in sediment from IODP Exp. 336, noting that phosphorous concentrations are greatest near the sediment-basement interface. This increase could be indicative of higher accumulation rates when those sediment layers were deposited, probably associated with hydrothermal plume scavenging and deposition near the spreading center (Defforey and Paytan 2015).

Salas et al. (2015) presented the first data from an in situ downhole tool (DEBI-t) that uses a Deep UV optical method to detect and image bacterial cells and spores on natural and opaque surfaces while avoiding autofluorescence interference. This new tool allows one to measure bacterial density and distribution of single cells to biofilms over spatial scales ranging from centimeters to microns. It was shown that microbial cell counts in Hole 395A at NP are greater than in bottom seawater. In addition, Beth Orcutt and colleagues used rocks from NP to examine autotrophy in both subseafloor and seafloor-exposed rocks. They found higher levels of incorporation of labeled bicarbonate into seafloor-exposed rocks as compared to subseafloor basalts, and the authors predict potential rates of carbon fixation in oceanic crust at similar levels to those predicted based on thermodynamics alone (Bach and Edwards, 2003).

Four other manuscripts related to microbial life in the rocks and crustal fluids at NP are currently in review. For example, Meyer et al. provide the first phylogenetic and functional description of an active microbial community residing in the cold oxic crustal aquifer at NP. Their results reveal an active, distinct, and diverse bacterial community engaged in both heterotrophy and autotrophy in the oxygenated crustal aquifer, providing key insight into the role of microbial communities in the ubiquitous cold dark subseafloor biosphere at NP. Two other studies examined the microbial community structure and constraints on microbial growth of NP rock samples collected during the drilling expedition (Baquiran et al. and Zhang et al.). Lastly, C-DEBI collaborator W. Bach examined catabolic energy for microbial life during water-rock reactions in the flanks of mid-ocean ridges, where basaltic and ultramafic rocks interact with circulating seawater. He concluded that a standing stock of 2.4 x 1028 cells may support Fe oxidation in basaltic ridge flanks, equivalent to about 10% of the sedimentary deep biosphere.

*Technical Accomplishments*

The NP program continues to push technology in areas that serve the development of borehole installations for experimentation. In looking towards the planned 2017 expedition, we are further developing an in situ flow meter that worked for a short period in the JdF CORKs. Flow meter data are highly desirable, because when coupled with pressure data, they permit calculation of crustal permeability and, by extension, the magnitude of fluid flow.

Other technical developments were undertaken by Tom Pettigrew, who designed all of the CORK systems to date. He finished his analysis and provided technical drawings that will allow us to deploy CORK-Lites in any of the cased legacy boreholes that have been drilled over the past 40 years. Given more than 50 legacy boreholes world-wide with a range of crustal settings (e.g., age, temperature, redox sate of the fluids), one can use these documents to develop a platform for studying biogeochemical processes within the basaltic crust. These drawings will be used for IODP Exp. 366 (December 2016-February 2017) to the Mariana forearc, where three new cased boreholes will be deployed within active serpentinite mud volcanoes. These cased boreholes are being designed to accommodate CORK-Lites that can be used to address a variety of research questions in this high pH (up to 12.5) environment.

**Summary of Problems and how they were Addressed During Review Period**

There were no major issues during the reporting period.

► See more at the [North Pond Major Program webpage](http://www.darkenergybiosphere.org/research/northpond.html)

► See References Cited in [[Appendix A](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-A-References-Cited.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-A-References-Cited.pdf)

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**d. Major Program: Dorado Outcrop**

**Led by:** Geoff Wheat, University of Alaska Fairbanks

**Background**

This study builds on decades of research that observed differences between measured and theoretical heat flow values in the ocean crust. Lister(1972) postulated that these differences resulted from the cooling of the crust by the circulation of seawater. The magnitude of this circulation is large, redistributing 10 TW (one fourth) of the Earth’s heat loss. Then, in 1977, the first seafloor hydrothermal system was discovered; however, such systems, driven by the intrusion of magma, account for 20% of the total convective heat loss from oceanic crust. The remaining heat loss is transported on the ridge flanks at much cooler temperatures, yet with a net fluid flux that is commensurate with that of rivers. Given this magnitude of fluid flow, it has been postulated that even a minimal (1-5%) loss or gain from seawater-crustal exchange could impact global geochemical budgets in the ocean; however, until recently such a representative system had yet to be sampled.

Off the west coast of Costa Rica on 23 Ma-old crust lies the Dorado Outcrop (DO), a small (0.5 km wide by 2 km long and 150 m high) basaltic outcrop that that trends southeast-northwest and is characteristic of typical ridge flank hydrothermal systems. In 2013 we surveyed DO using the autonomous underwater vehicle Sentry and the remotely operated vehicle Jason II (AT26-09). Surveys generated a bathymetric map from which visual and thermal surveys located sites where crustal fluids vented and placed them within a geologic context. The outcrop consists of basaltic pillows and sheet flows with linear faults that are tens to hundreds of meters long and in the general trend of the outcrop. Surprisingly hydrothermal fluids do not currently vent from these linear features.

Instead, diffuse hydrothermal activity was identified from thermal anomalies determined from temperature probes mounted on the ROV and AUV. Such anomalies guided closer inspection with a manipulator-held device. Over one hundred thermal measurements were made with the warmest recorded temperature of 12.3**°**C, well above the bottom water temperature (1.85**°**C). Most of the hydrothermal flow occurred ubiquitously along the southwestern portion of the outcrop with the most vigorous site that spans hundreds of square meters (Marker K). In 2013, spring samples were collected and continuous fluid samplers (OsmoSamplers), and temperature loggers were deployed. Because of the diffuse nature of the springs, we developed a novel syringe-based fluid sampler that we used in 2014 with the submersible Alvin during which we recovered samplers and sensors, collected additional fluids, and measured dissolved oxygen in situ.

**Summary of Significant Accomplishments During Review Period**

*Operational Accomplishments*

Last year’s report focused on the accomplishments from the 2013 AUV and ROV operations (AT26-09) that ended December 24, 2013. Here we report the on the major accomplishments from the 2014 submersible operations (AT26-24) that ended December 12, 2014. During the expedition we completed ten Alvin dives, collected thirteen gravity cores, conducted one CTD hydrocast, and completed four surveys using the hull-mounted bathymetric mapping system. Through these activities we collected hundreds of samples for hydrologic, biogeochemical, and microbial studies, all of which have been the focus of shore-based analysis undergoing a spectrum of analytical and modeling efforts. Samples and data collected include:

* Kilometers of high resolution bathymetric with the hull-mounted system,
* Video and still images of Dorado Outcrop,
* Discrete samples of spring fluids (19 microbial and 35 chemistry),
* Measurements of heat flow (4),
* Measurements of temperature (31),
* Sediment push cores (50),
* Rocks (30),
* Bottom water via Niskin bottles (8) on Alvin and one CTD,
* Discrete dissolved oxygen measurements (26),
* A three-day and a four day record of dissolved oxygen and temperature at two (2) sites,
* Year-long record of temperature at five (5) sites with two sensors at each site,
* Continuous fluid sampling for one year at four (4) sites,
* Year-long enrichment experiments at four (4) sites.

These accomplishments were greatly aided with the help of the Alvin team. They seamlessly rig the oxygen optode, heat flow probe, and thermistor for real-time measurement within the sphere and provided quality navigation that minimized transit times on the seafloor.

*Scientific Accomplishments*

Much of the focus for the Alvin dives in 2014 were on the collection and sensing of pristine spring fluids for biogeochemical and microbial analysis and the recovery of sensors, samplers, and experiments to constrain biogeochemical pathways and activity. Based on visual observations, discrete measurements of dissolved oxygen, dye experiments, three-day and four-day continuous records of dissolved oxygen and temperature, and year-long temperature and chemical records from probes and OsmoSamplers, the rate of flow from these springs varies on time scales of hours to days to years.

Data and samples from the two DO expeditions (AT26-24 and AT26-09) form the foundations for a series of manuscripts. Critical findings in three manuscripts include:

* the presence of dissolved oxygen in the chemically altered (relative to bottom seawater) spring fluids that, when extrapolated globally, have an impact on oceanic geochemical budgets (Wheat et al.)
* a survey of 16S rRNA gene sequence diversity of communities on seafloor rocks reveal a community that is dominated by Gamma-, Alpha-, and Deltaproteobacteria, and Thaumarchaeota with much greater richness and diversity than in the surrounding seawater and when these results are integrated with existing datasets that provide a global distribution of seafloor basalt experiments the results suggests that substrate age correlates with community structure (Lee et al.);
* simulations of outcrop-to-outcrop crustal hydrology that match regionally expected fluid fluxes and new findings that local convection in and out of individual, large outcrops also removes a significant fraction of lithospheric heat (Lauer et al.)

*Technical Accomplishments*

Technical accomplishments for Expedition AT26-24 included (1) submersible integrations of an Aanderaa Optode for discrete measurements of dissolved oxygen, (2) development of a dye releasing manifold for assessing fluid flux, (3) the redeployment of RBR oxygen and temperature probes, which were developed for NP and are now commercially sold by RBR, Inc., and (4) and hydrologic models for elucidating subsurface flow patterns and magnitude.

**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](http://www.darkenergybiosphere.org/research/dorado.html)

► See References Cited in [[Appendix A](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-A-References-Cited.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-A-References-Cited.pdf)

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**e. Other Field Projects**

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 that received particular attention in 2015, identifying key C-DEBI personnel involved:

***Atlantis Massif Serpentinization and Life***. International Ocean Discovery Program (IODP) Expedition 357 (26 October - 11 December 2015) used seabed drills to collect hard rock core samples from an actively serpentinizing subseafloor environment, with a primary scientific objective to investigate the variation and connectivity of microbial life in this subsurface environment. This expedition included the development of new sensor packages, tracer delivery systems, and borehole plug systems to enable microbiological and geochemical investigation with seabed drill systems. (Beth Orcutt)

***Bay of Bengal Subseafloor Biogeochemistry.*** IODP Expedition 353 (29 November 2014 – 29 January 2015), “iMonsoon”, included a microbiology component focused on microbially mediated nutrient transformations. These include novel metabolic pathways suggested by geochemical data and thermodynamic calculations. Samples were taken for chemical analyses including dissolved gases, as well as material for cultures and nucleic acid extraction when in International Waters. (Steven D’Hondt, Eric Boyd)

***Pescadero Basin, Gulf of California*.** This MBARI-led expedition discovered a unique carbonate-hosted vent field in the Gulf of California in April 2015. Rock, sediment, and fluid samples were collected for geochemical, mineralogical, and microbiological analysis. DNA-based diversity surveys, anaerobic enrichment cultivation, and microcosm experiments were conducted and laboratory based analyses to characterize the activity of specific microbial lineages associated with different minerals at temperatures ranging from 10 to 80ºC are ongoing. (Victoria Orphan)

***Subseafloor Life at Axial Seamount.*** This NSF and NOAA/Pacific Marine Environmental Laboratory Vents Program cruise, with leveraging from the Gordon and Betty Moore Marine Microbiology Initiative, was (14-29 August, 2015) aboard the R/V Thomas Thompson to continue geophysical, chemical, and biological time-series at this very active submarine volcano. This included a RAPID response effort related to the April-May 2015 eruption at Axial, as detected by the OOI Cabled Array. One important component of the cruise was to collect fluid and microbial samples from Axial vents to better understand the chemistry of the system, their subseafloor microbial communities, and how they change with time. A highlight this year was the successful use of an incubator to determine if in-situ microbiology experiments on the seafloor produce different results than those in the laboratory. (Julie Huber)

***Baltic Sea Basin Paleoenvironment.*** Two expeditions to the Baltic Sea in 2013 and 2014 used ocean sediment drilling and coring to obtain water and sediment samples. Analyses of these samples continued in 2015 to explore the variations in sedimentation and organic matter deposition throughout the recurrently waning and waxing of the Scandinavian Ice Sheet. One component of this study is to analyze the shifts in active microbial community structure and function throughout as it corresponds to climatic changes. Samples were analyzed shipboard for geochemical constituents, with continuing on-shore work-up for single-cell genomics, metagenomics, transcriptomics, and cultivations (Jan Amend, Brandi Kiel Reese, Karen Lloyd).

► See related C-DEBI Contributed Publications in [[Appendix L](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-L-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)

# f. 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 47 funded projects active in 2015 is provided in [[Appendix B](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-B-Active-Grants-and-Fellowships.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-B-Active-Grants-and-Fellowships.pdf). The breakdown of active grants and fellowships is as follows: 15 small research projects with funding up to $50k, 3 special biomolecular grants with funding up to $150k, 6 special synthesis-field programs grants with funding up to $100k, 7 graduate student fellowships with funding for 1-2 years, 11 postdoctoral fellowships with funding for 1-2 years, 3 education and outreach grants with funding up to $50k, 1 research and travel exchange grant that requires matching funds, and 1 additional grant for a project of special interest to C-DEBI. Sixty-eight different individuals, representing 37 institutions received financial support for these projects.

While some of the grants and fellowships mentioned above support research related to the major programs and other field projects, several awards support experimental or analytical investigations relevant to C-DEBI. These include analyses of samples and data from deep subseafloor sites, laboratory studies of microbial activity, and investigations of analog environments. Of note is the special call for projects that emphasized 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. Six awards (~$100k each) were made to: PI Eric Boyd (Assistant Professor at Montana State University) to define the interplay between oxygen, organic carbon, and metabolism in subseafloor sediment communities; PI Rick Colwell (Professor at Oregon State University) to quantify the differences in microbial communities at interfaces between volcanic ash, turbidite, and clay layers in the subsurface; PI Colleen Hansel (Associate Scientist at the Woods Hole Oceanographic Institution) to elucidate the extent and composition of mineral-hosted carbon in deep subsurface sediments; PI Susan Lang (Assistant Professor at South Carolina University) to investigate the influence of free energy availability by sulfate reduction in resource utilization and carbon flow by model alkaliphilic prokaryotes; PI Grieg Steward (Professor at the University of Hawai’i) to separate viruses from a 10,000 L sample of basement fluid, and analyze fractions for morphology, genomes, and proteomes; and PI Andreas Teske (Professor at the University of North Carolina) to combine microbiological, geochemical, and sedimentological analyses to investigate subseafloor life and sediment environments in the Guaymas Basin.

C-DEBI also funded and organized three workshops in 2015. The first one focused on research accomplishments and future directions in the sedimentary subseafloor biosphere. It was held at USC June 25-26 and was led by Karen Lloyd (University of Tennessee, Knoxville) and Co-PI D’Hondt. The second workshop, held at Harvard University July 9-10 and organized by Jason Sylvan (Texas A&M University) and Co-PI Huber, reviewed the state of knowledge in the microbial ecology of subseafloor basement environments, including igneous rocks and crustal fluids. The third workshop, held at Sandbjerg, Denmark September 21-25 explored the limits of microbial life and the biological demand for energy. It was co-organized by PI Amend, Tori Hoehler (NASA Ames), and Bo Barker Joergensen (University of Aarhus) and funded jointly by C-DEBI, the University of Aarhus, and the Aarhus Center for Geomicrobiology.

► See related C-DEBI Contributed Publications in [[Appendix L](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-L-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)

## 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. In Phase 1, C-DEBI focused primarily on the exploration and discovery of subseafloor ecosystems, with most studies concentrated at four major sites: Juan de Fuca Ridge flank, South Pacific Gyre, North Pond, and the Dorado Outcrop. In Phase 2 (2015-2020), C-DEBI will develop an integrated understanding of microbial subseafloor life covering and connecting the molecular, cellular, and ecosystem scales. Maintaining highly multidisciplinary and interdisciplinary approaches, C-DEBI will emphasize microbial ecology while ensuring that essential context is provided through studies and advances in geochemistry, hydrology, oceanography, and related disciplines. The three overarching research themes are (1) fluxes, connectivity, and energy; (2) activities, communities, and ecosystems; and (3) metabolism, survival, and adaptation. C-DEBI research projects target two distinct subseafloor biosphere environments—the igneous ocean crust and overlying sediments—that have historically been studied independently; field investigations of these environments are complemented by coordinated laboratory studies and ecosystem modeling activities. C-DEBI is led by five Co-PIs and five senior scientists from eight U.S. universities and research labs, but seeks to build and leverage scientific, educational, and technological partnerships with numerous other 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:** Transfers of fluid, heat, solutes, carbon, and microbes are quantified within and between subseafloor biomes, and between the subseafloor and the overlying ocean; the nature of energy sources available to microbes in these ecosystems is determined; and the next generation of coupled fluid-energy-biochemical-microbial models is developed.

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| **Metric** | **Status/Problems** |
| Quantify transfers of fluid, heat, solutes, carbon, and microbes within and between subseafloor biomes, and between the subseafloor and the overlying ocean 1. Carry out time-series observations and sampling at Juan de Fuca and North Pond to resolve the extent of natural variability (within and between biomes), determine environmental controls on crustal microbial community composition, and assess how this variability impacts flows and connections
2. Continue pioneering cross-hole tracer experiment in the ocean crust at Juan de Fuca, where preliminary data demonstrated, for the first time, a direct hydrogeologic connection between sites that are separated by hundreds of meters, and solute and dissolved gas travel-times of hundreds of meters to kilometers/year
3. Collect long-term samples and data loggers at the Dorado Outcrop and conduct additional surveys at this site of massive discharge of low-temperature ridge-flank hydrothermal fluid
 | Pending |
| Determine the nature of energy sources available to microbes in these ecosystems1. Map the distributions of electron acceptors and electron donors regionally and globally as a function of depth at a range of spatial scales.
2. Quantify metabolic reaction energetics as well as fluxes of electron acceptors and donors by combining internally consistent thermodynamic data, available kinetic parameters, and reactive transport modeling
 | Pending |
| Develop the next generation of coupled fluid-energy-biochemical-microbial models1. Combine existing physical and thermal models with rate constants for primary reactions and transport (advection and diffusion) that involve solutes in basement fluids; then attempt to couple these with microbial processes to increase the model complexity
2. Test, calibrate, and apply coupled geochemical-microbiological models to a variety of seafloor and subseafloor environments
 | Pending |
| Publish 25 (in aggregate) papers in this research theme | Pending |
| Publish 5 (in aggregate) method/instrument papers demonstrating new techniques and tools developed and/or applied in this research theme | Pending |

**Target 2:** The composition of subseafloor microbial communities and the functional potential of these communities are illuminated, based on the diversity of metabolic activities and interactions with the physicochemical aspects of the system.

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| **Metric** | **Status/Problems** |
| Determine community composition, functional potential, and patterns of natural selection in subseafloor ecosystems1. Quantify the number, diversity, and relative abundances of microbes at multiple taxonomic levels—from domain to “species-level” operational taxonomic units (OTUs), ecotypes, and oligotypes
2. Determine the functional potential embodied in these communities
3. Integrate data on community composition and microbial activities to identify how sources of energy and microbial interactions drive natural selection in subseafloor ecosystems
 | Pending |
| Determine metabolic activity of subseafloor microbial communities1. Document actual rates of in situ activities using gene expression in sediment and rock samples
2. Identify potential activities in laboratory experiments using subseafloor samples incubated with isotope-labeled substrates
3. Closely examine microbe-mineral interactions in conjunction with activity measurements in in situ incubations and laboratory microcosms
 | Pending |
| Advance understanding of subseafloor microbe-virus interactions1. Integrate correlation network techniques using subseafloor archaeal, bacterial, microeukaryote, and viral diversity datasets combined with microbial activity measurements
2. Incorporate the isotopic and diversity datasets collected as part of 2.a. and 2.b. to develop a food web model in combination with statistical diversity-based networks
 | Pending |
| Publish 25 (in aggregate) papers in this research theme | Pending |
| Publish 5 (in aggregate) method/instrument papers demonstrating new techniques and tools developed and/or applied in this research theme | Pending |

**Target 3:** A ‘portfolio’ of selected model subseafloor organisms is built, and their physiological and genetic traits are characterized; in addition, these microorganisms are used to investigate energy and carbon use for growth and maintenance under kinetically limiting conditions and to determine rates of metabolism under specific conditions.

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| **Metric** | **Status/Problems** |
| Isolate and characterize novel bacteria and archaea from diverse subseafloor habitats1. Enrich subseafloor bacteria and archaea from sediment, crustal fluids, and rock samples, using, among others, plugged flow, chemostat, and hanging sponge reactors
2. Fully characterize novel organisms, including their genomes
3. Interrogate their abundance and activity in the original sample to help infer their ecological roles
 | Pending |
| Examine fundamental physiology of subseafloor microbes under conditions of low growth rates and low energy flux1. Use long-term chemostat-like culturing systems to study the coupling of catabolism and growth in the Chloroflexi
2. Use down-flow hanging sponge bioreactors to explore the molecular and physiological underpinnings of the hypothesis that archaea may be low-energy specialists and well adapted to the energetic extremes that define many subseafloor environments
 | Pending |
| Perform adaptive evolution and long-term survival experiments with subseafloor microbes to characterize molecular genetic signatures associated with particular phenotypes1. Use subseafloor isolates to determine the genotypic, phenotypic, and biochemical and physiological bases for metabolic traits
2. Develop genetic markers for model organisms to be used in competition experiments
 | Pending |
| Publish 25 (in aggregate) papers in this research theme | Pending |
| Publish 5 (in aggregate) method/instrument papers demonstrating new techniques and tools developed and/or applied in this research theme | Pending |

**Target 4:** Field investigations at the four ‘major sites’ are largely completed and environmental data and samples are coupled with complementary laboratory experiments and numerical modeling across the three research themes.

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| **Metric** | **Status/Problems** |
| Additional (and final) C-DEBI research cruises to North Pond, Juan de Fuca, and Dorado Outcrop are scheduled1. Collect samples for laboratory analyses and experiments
2. Collect environmental data for use in experiments and ecosystem modeling
 | Pending |
| Convene workshops and conference sessions1. Develop approaches to integrate results from field, lab, and modeling studies
2. Present synthesis results from major field sites
 | Pending |

**Target 5:** The new C-DEBI senior scientists are integrated in all aspects of the Center, and cross-disciplinary and cross-institutional research training is thriving through our grants programs, thereby expanding the community of deep biosphere researchers, technologists, and educators.

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| **Metric** | **Status/Problems** |
| Provide substantial research funds to the 5 Co-Investigator labs as well as to the 5 new senior scientist labs | Met |
| Award $1M in research grants/fellowships annually (for the first 3.5 years) to predominantly graduate students, postdoctoral scholars, and other junior researchers through annual RFPs | Pending; a current call for proposals is due 1/31/16. |

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

The research plans for the next reporting period remain as stated in the Phase 2 (renewal) proposal. Field-based research and associated sample analyses will continue at several sites, including North Pond, Juan de Fuca Ridge flank, Dorado Outcrop, the Shimokita coal beds, sediments in the Baltic Sea Basin, and the Atlantis Massif, among others. Research in Theme 1 will constrain the extent, variability, and controls on fluxes and connectivity within subseafloor biomes and between the subseafloor and the overlying ocean; map geochemical energy sources in subseafloor ecosystems at a range of spatial scales; and develop and test the next generation of coupled geochemical-hydrological-microbial models for subseafloor ecosystems. In Theme 2, we will determine community composition, functional potential, and patterns of natural selection in subseafloor ecosystems; determine metabolic activity of subseafloor microbial communities; and advance understanding of subseafloor microbe-virus interactions. In Theme 3, we will isolate and characterize novel bacteria and archaea from diverse subseafloor habitats; examine fundamental physiology of subseafloor microbes under conditions of low growth rates and low energy flux; and perform adaptive evolution and long-term survival experiments with subseafloor microbes to characterize molecular genetic signatures associated with particular phenotypes. Partnering with the Sloan Foundation-funded Deep Carbon Observatory (DCO), C-DEBI is also planning to hold two workshops: one on ‘deep cultivation’, which will focus on existing and future culturing techniques for exploring uncultivated archaea, bacteria, viruses, and eukarya from the deep Earth; and another on ‘origins and movements of subsurface microbes’, which will integrate groundwater dating, hydrogeological flow, transport modeling, genomics, and evolutionary microbiology.

# 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. Our overall strategic plan focuses on three key areas: mentoring, training, and outreach.

This reporting period focused on 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/postdoctoral researchers. Center staff and researchers identified strategic partners to support specific outreach objectives for each of these targeted communities.  Support ranged from the creation of an eBook for K-6 students to the integration of research and education via 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 third year, the C-DEBI flagship program Community College Research Internship for Scientific Engagement (CC-RISE) continued at the University of California, Santa Cruz (UCSC) and expanded to the Marine Biological Laboratory (MBL). CC-RISE is a non-residential REU-style program, led by Education, Outreach, & Diversity Director Stephanie Schroeder at USC, by Adina Paytan at UCSC, and by Julie Huber and Gretta Serres at MBL. CC-RISE was not held at USC in 2015 due to the resource conflict of USC hosting the Special Olympics. Seven academically competitive community college students spent eight intensive summer weeks working in labs at UCSC (5) and MBL (2). Students spent 40+ hours in the lab, conducting research and participating in professional development seminars ranging from how to read/write a scientific paper to how to apply to graduate school. In the post-program survey, students commented that they felt prepared to succeed at a four-year university and their participation in CC-RISE allowed them to expand their career options; they also indicated that the program met or exceeded their expectations (see the CC-RISE student and mentor evaluations in [[Appendix C](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-C-CC-RISE-Student-Evaluations.xls)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-C-CC-RISE-Student-Evaluations.xls) and [[Appendix D](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-D-CC-RISE-Mentor-Evaluations.xls)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-D-CC-RISE-Mentor-Evaluations.xls)). Four students transferred to four-year universities in the fall (UCSC, UC Berkeley, UC San Diego, and U Massachusetts, Dartmouth). C-DEBI Associate Director Julie Huber and Co-PI Andy Fisher were mentors for the program, and also gave seminars to students in the program about their respective research. The NSF-STC educational supplement awarded to C-DEBI will be used in the coming years to enhance our undergraduate research opportunities specifically by supporting more students in our REU and CC-RISE programs.

C-DEBI supported a major undergraduate research internship program targeting underrepresented minorities, the Genomics and Geobiology Undergraduate Research Experience (GGURE) consisting of both a part-time program during the academic year and a full-time program over 10 summer weeks. This program builds on a 12-year effort led by Phase 2 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) was adapted to emphasize genomics, geoscience and other STEM fields and continues to utilize external evaluation to assess the quality and outcome of the program. Students reported that their experience in the summer program made them more likely to include research in their career goals. Additionally, the weekly journal club meetings provided an opportunity for students to delve into various research topics while forming a research cohort (see the evaluation in [Appendix E](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-E-GGURE-Evaluation.pdf)).

In addition to GGURE, C-DEBI sponsored two student research internships through the NSF STC Tribal Initiative: Integrating Traditional Ways of Knowing with Western Science. This initiative was designed to broaden the participation of Native Americans, Native Alaskans, Native Hawaiians, and Pacific Islanders in STEM by creating structured opportunities through research collaborations, a distinguished lecture series, a “role models” initiative, research experiences for undergraduates, major conference attendance, and joint recruitment of Native American students. C-DEBI EOD Director Schroeder participated in the steering committee for this initiative and C-DEBI investigator Dr. William Brazelton at the University of Utah hosted two undergraduate interns:  Akamu Jaber (Native Hawaiian), and Abby Jessell (Cherokee).  Akamu and Abby collaborated on a research project to characterize the microbial diversity of groundwater aquifers in southern Utah.  As part of this initiative, Akamu and Abby interacted with 7 other undergraduate interns working at 3 other participating STCs and also attended the 2015 National Conference of the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS) in National Harbor, MD.  In evaluation, both Akamu and Abby described their experience as valuable and formative for their continuing education/graduate school plans.

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 funded student participation and included deep biosphere content in the curriculum with C-DEBI lecturers (USC faculty Jan Amend and Doug LaRowe, Colorado School of Mines faculty John Spear, University of Tennessee faculty Karen Lloyd and Andrew Steen). Students were surprised at the true interdisciplinary nature of biology and geology and valued the collaboration with scientists outside their fields. All fourteen respondents to the evaluation reported that their expectations for the course were met (see the evaluation in [Appendix F](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-F-GeoBio-Course-Evaluation.pdf)).

##### Another flagship program is our Global Environmental Microbiology (GEM) course, which targets underrepresented early undergraduate students. Now in its fifth year, this field-based, hands-on, four-week program for was led by USC faculty John Heidelberg and Eric Webb with directional support from EOD Director Stephanie Schroeder. 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 conducted a comprehensive evaluation of the program via surveys to students. Greater than 80% of the GEM students reported that the course had a significant impact on their educational goals and careers. Students commented that the hands-on lab experience and field work were the most meaningful components of the course (see the evaluation in [Appendix G](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-G-GEM-Course-Evaluation.pdf)).

C-DEBI material was also integrated into several undergraduate courses and activities led by C-DEBI scientists. C-DEBI research was also presented to other undergraduate and graduate institutions with C-DEBI Leaders as invited speakers. Andreas Teske, Jennifer Glass, Esther Schwarzenbach, and Frank Robb all incorporated deep biosphere information into lectures and seminars at their respective institutions in both introductory and advanced courses. Jennifer Glass and Karen Lloyd organized seminars at the 2nd annual Southeastern Biogeochemistry Symposium (March 28-29, 2015 at Georgia Tech). Giora Proskurowski and Robert Pockalny mentored undergraduate students in deep sea biogeochemistry and database projects, respectively. In addition, the C-DEBI community mentors undergraduate students, graduate students, and postdoctoral researchers 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.

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| **Activity Summary** | **Postsecondary Programs** |
| Led by | Dr. Stephanie Schroeder, Dr. Adina Paytan, Dr. Steven Finkel, Dr. William Brazelton, Dr. Jan Amend, Dr. John Spear, Dr. Andrew Steen, Dr. Doug LaRowe, Dr. John Heidelberg, Dr. Eric Webb, Dr. Julie Huber, Dr. Gretta Serres, Dr. William Brazelton, Dr. Robert Pockalny, Dr. Andreas Teske, Dr. Giora Proskurowski, Dr. Esther Schwarzenbach, Dr. Jennifer Glass, Dr. Frank Robb, Dr. Karen Lloyd, Dr. Steve Moore, Dr. Geoff Wheat |
| Intended Audience | General audience |
| Approximate Number of Attendees  |  924 |

##### ► See more at the [CC-RISE webpage](http://www.darkenergybiosphere.org/education/undergrads/ccrise.html)

##### ► See more at the [Geobiology Course webpage](https://dornsife.usc.edu/wrigley/geobiology/)

##### ► See more at the [GEM Course webpage](http://www.darkenergybiosphere.org/education/undergrads/undergradscourse.html)

**3. Participation of Center Students and Postdoctoral Researchers 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 ~275 graduate students and postdoctoral researchers.C-DEBI invests in the next generation of subseafloor researchers via its fellowship program (addressed in the [Research section II.2.f](#_f._Other_Projects)), funding 10-15 graduate students and postdoctoral researchers each year. C-DEBI has added a Broader Impacts component to the fellowship call, details provided in the **Integration of Research and Education** section. An emailing list for C-DEBI graduate students and postdoctoral researchers including these fellows supports a private forum for participants to discuss topics pertaining to their research, professional development, and post employment/fellowship opportunities. EOD Director Stephanie Schroeder also sends weekly emails to this 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 virtually attending microbiology webinars.

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. C-DEBI is currently seeking nominations for speakers in the upcoming year.

C-DEBI partnered again with MARINE (Monterey Area Research Institutions’ Network for Education, a consortium of 7 Monterey area institutions) at the Moss Landing Marine Laboratories to engage graduate students and postdoctoral researchers in an all-day professional development workshop, *Making the Transition from Graduate Studies to the Interdisciplinary Workforce*, to better prepare them as future science leaders. The goal of the workshop was to provide C-DEBI and MARINE graduate students/early career professionals with an opportunity to explore the variety of interdisciplinary science and environmental career pathways, as well as prepare a CV/resume and practice career-networking skills with these careers in mind. With guidance from Mr. Roy Blitzer, an executive coach & management consultant for the Stanford Careers Center, the 50 participants learned the difference between CVs and resumes in relation to potential careers and worked in small groups to improve their own. Mr. Blitzer also discussed the importance of informational interviewing (i.e., networking), and participants created lists of questions to ask when informational interviewing. Using a speed dating technique (rotating groups every 10 minutes), participants practiced career-related informational interviewing and “power” networking skills with a panel of expert representatives from a variety of related fields (science policy, academics, government research, etc.). On average, participants were very satisfied with the workshop (8.59 on a 10-point scale; see the evaluation in [Appendix H](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-H-Professional-Development-Workshop-Evaluation.xls)) and found the format to be engaging.

C-DEBI graduate student and postdoctoral fellows individually participated in professional development activities at their home or local institutions. These activities ranged from giving guest lectures to mentoring undergraduates. Alexander Michaud developed an activity with elementary school students to convey how glaciers moved while Stephanie Carr and Olivia Nigro presented lessons about the deep biosphere, also targeting elementary aged students. Fellows also had roles in organizing at local and national conferences such as the Expanding Your Horizons Hawaii where Olivia Nigro served as a co-chair for the conference in addition to being the liaison for the Hawaii Graduate Women in Science chapter. At the SACNAS (Society for the Advancement for Chicanos and Native Americans in Science) National Conference, Rosa Leon Zayas served as a mentor and poster judge. Alexander Michaud and Beate Kraft also gave lectures to undergraduates and other researchers about their research.

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.

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| **Activity Summary** | **Professional Development** |
| Led by | Dr. Stephanie Schroeder, Dr. Laura Good, Roy Blitzer, Alexander Michaud, Dr. Stephanie Carr, Dr. Olivia Nigro, Dr. Rosa Leon Zayas, Dr. Beate Kraft |
| Intended Audience | Graduate students, postdoctoral researchers |
| Approximate Number of Attendees  | 775 |

► See more at the [Networked Speaker Seminar Series webpage](http://www.darkenergybiosphere.org/resources/speakerseries.html)

► See more at the [C-DEBI Ethics Policy webpage](http://www.darkenergybiosphere.org/internal/ethics.html)

**4. Professional Development for K-16 Instructors**

Our strategy for reaching educators is two-fold: professional development opportunities for educators who wish to learn in 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, aquariums, or other settings.

In April and October, 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 15 instructors (3 participated in both workshops) participated from 11 Los Angeles-area community colleges (College of the Canyons, Pasadena City College, Los Angeles Harbor College, Santa Monica College, Cerritos College, Fullerton College, Rio Hondo College, East Los Angeles College, El Camino College, El Camino College the Compton Center, and Orange Coast College). Based on evaluations from both of the workshops (see [Appendix I](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-I-CC-Instructor-Workshop-Evaluations.xlsx)), 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 2016).

The K-16 Teacher Small Grants program is a follow-up program for participants in previous C-DEBI K-16 Teacher Workshops (e.g., CC Instructors Workshop, MBARI EARTH Workshop, Ali’i Workshop) to stimulate and track teacher application of workshop curriculum to students. One grant ($2490) was awarded for 2014-2015. Teacher Mark Friedman at Animo Leadership Charter High School (Inglewood, CA) expanded classroom activities and field experiences for 98 Marine Biology Club students by bringing students to various science lectures around the Los Angeles area. Funds were also used for his own professional training where Mr. Friedman presented C-DEBI material at the National Association of Biology Teachers, the National Science Teachers Association, and the international Evolution2015 conferences. He also purchased new microscopes and aquatic ROVs that were used on an educational, near-shore ocean cruise via the City2Sea research vessel which brings inner-city kids aboard the R/V Streamliner to inspire them with the abundance of marine life found just outside of Los Angeles.

One of the two E&O Small Grants funded last year was to the College of Exploration for the [Collaborative Development of C-DEBI Resources for Community Colleges](http://www.darkenergybiosphere.org/education/proposalsFunded.html#tuddenham) which was a continuation of the 2013 C-DEBI online workshop “Microbes Down Below! Exploring Life Beneath the Ocean Floor” that was specifically designed for community college instructors and funded through a prior E&O small grant. The grant funded the collaborative development of online toolkits of educational materials and resources that community college instructors can use to teach about C-DEBI research and the deep biosphere and that is also valuable for high school teachers. Comments and evaluations from community college instructors and scientists who participated in the course provided valuable guidance. The kits are aligned with specific community college course subjects and were produced through a collaborative process involving scientists, community college faculty, graduate students and education and technology experts. These toolkits are freely available at the College of Exploration’s C-DEBI learning platform.

C-DEBI researchers collaborated with K-16 instructors to introduce C-DEBI material into the classroom. Postdoctoral researcher Ileana Perez-Rodriguez (USC) and Assistant Professor Jason Sylvan (Texas A&M, College Station) worked with community college instructors to develop curricula based on their research at the C-DEBI Community College Instructor Workshop.

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| **Activity Summary** | **Professional Development for K-16 Instructors** |
| Led by | Dr. Stephanie Schroeder, Peter Tuddenham, Dr. Jason Sylvan, Dr. Ileana Perez-Rodriguez, Dale Stanley |
| Intended Audience | General audience |
| Approximate Number of Attendees | 113 |

##### ► See more at the [Teacher Small Grants webpage](http://www.darkenergybiosphere.org/education/teachers/teacherSmallGrants.html)

► See more at the [College of Exploration’s C-DEBI Toolkits for Community Colleges webpage](http://www.coexploration.org/C-DEBI/)

**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 subseafloor research. C-DEBI supported the High School Marine Science Camp for a fourth year. 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. Co-PI Geoff Wheat launched the Seafloor Science and ROV Summer Camp for 6th-8th graders, which emphasizes technology to conduct subseafloor research. Wheat also contributed to five web articles/blog posts to promote the summer camp and provided information for a piece on the Dorado Outcrop site by the Al Jazeera America group. Associate Director Julie Huber contributed to general audience science articles focused on the deep biosphere. She also was a blog contributor for the Axial Seamount Expedition 2015.

C-DEBI’s general outreach activities range from interactive programs that involve a wide audience to promoting C-DEBI through popular media. David Emerson, Jason Sylvan, and Jennifer Glass all contributed to various blogs where they recounted life as scientists and all three of them gave lectures to the general public at venues including Café Scientifique. Linda Chilton spoke about deep sea exploration to students at Animo High School, while Virginia Edgcomb spoke to middle schoolers about subsurface microbiology. One of the two E&O Small Grants funded this year was to the Consortium for Ocean Leadership’s Deep Earth Academy who created a free interactive children’s eBook based on C-DEBI. [“Where Wild Microbes Grow: The Search for Life Under the Seafloor”](http://joidesresolution.org/node/4185) was written to meet Common Core and Next Generation Science standards and uses text, illustrations, and videos to teach K-8 students about intraterrestrial life and the nature of science. The eBook debuted on iTunes in October and has already reached 4000 people. Various C-DEBI researchers contributed to the book and are featured characters in the story.

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| **Activity Summary** | **Targeted K-12 Programs** |
| Led by | Dr. Stephanie Schroeder, Linda Chilton, Kevin Kurtz, Dr. Geoff Wheat, Dr. David Emerson, Sharon Cooper, Dr. Virginia Edgcomb, Dr. Jennifer Glass, Dr. Jason Sylvan |
| Intended Audience | General audience |
| Approximate Number of Attendees  | 4456 |

# ► See more at the [JOIDES Resolution’s Where Wild Microbes Grow eBook webpage](http://joidesresolution.org/node/4185)

**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 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 mentioned above, C-DEBI also supported a number of other training programs including the STC Tribal Initiative, GeoBiology course and more.

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 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 and he ran camps in both Monterey and Mississippi in 2015. In addition, four undergraduates were trained as ROV camp interns and served as mentors for the program. Through [his C-DEBI E&O Small Grant](http://eel.csumb.edu/c-debi-catalina-rovs), Steven Moore (California State University Monterey Bay, CSUMB) has worked with middle, high school, and college students promoting ROV science. Moore has used the ROVs in the undergraduate classroom, and students in turn demonstrated the ROVs at Monterey Wharf as part of the CSUMB’s Marine Science Club and used the ROVs for their own senior research projects. Two CSUMB undergraduates joined scientists on a 10-day cruise where the ROVs were used to explore biodiversity in the Gulf of Mexico. Participant numbers from both Wheat and Moore’s programs are reflected in the **Community College, Undergraduate, and Graduate Programs** section above.

 In addition, Steven Moore and his students built six sophisticated ROVs, three of which are located at the Wrigley Institute for Environmental Studies (WIES) on Catalina Island. USC staff members 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.

As mentioned above, a new component of the graduate student and postdoctoral researcher fellowship program is the inclusion of a Broader Impacts statement in their application. Fellows will gain experience writing broader impact statements and also be required to participate in an E&O activity, ranging from developing an activity at an Informal Science Education center to mentoring a community college student. Fellows will coordinate with EOD Director Stephanie Schroeder to ensure the activities are purposeful and relevant to C-DEBI outreach. Resulting products will be made available on the C-DEBI webpage.

**7. Performance with Respect to the Strategic Implementation Plan**

 **Goal:** *To bring C-DEBI research and the role of subseafloor microbes to the forefront by: 1) increasing microbiology literacy in the general public and at the K-12 levels; 2) engaging and retaining students in STEM fields; and 3) training the next generation of subseafloor researchers*. In our K-12 and general public activities, we rely heavily on partnerships with established organizations for whom these are the core target audiences. At the undergraduate level, we focus heavily on community college students and students from underrepresented minorities, because we see a myriad opportunities for some of the highest educational impact. Our most established education entity targets graduate students and beyond; here, our vision is to provide training in state-of-the-art technologies and instrumentation, together with mentoring in science communication, proposal preparation, project management, and other aspects of professional development.

Our *core* *objectives* in K-12 education/general public are to:

* 1. introduce C-DEBI content (e.g., the subseafloor biosphere, extreme microbiology, science and technology) into K-12 classrooms through professional development workshops for educators;
	2. provide hands-on science opportunities for students to engage them in microbiology and oceanography; and
	3. engage the general public in discovery science using public seminars, outreach activities, and social media.

Our *core* *objectives* in undergraduate education are to:

* 1. attract early and potentially undecided undergraduate students into STEM majors and strengthen their interest and passion for science and research; and
	2. provide cutting-edge university research opportunities, especially for community college students and members of underrepresented minorities.

Our *core* *objectives* in graduate and postdoctoral education are to:

* 1. train and nurture the next generation of subseafloor researchers; and
	2. provide professional development opportunities to allow them to expand their transferable skills.

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| **Objective** | **Metric** | **Status/Problems**  |
| 1.2 | 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, SeaGrant Summer Marine Camp, and guest speakers/lecturers in classrooms or special events | Exceeded |
| 1.1 | Award 2 E&O small grants and 3 K-16 teacher grants to fund the development of educational opportunities and materials on marine deep biosphere topics and to support K-16 teachers who have attended a C-DEBI teacher training program and have incorporated C-DEBI content into their classrooms, respectively | Partially met. During the transition between Phase 1 and Phase 2, no E&O small grants were awarded; a current call is pending with applications due 1/31/16. One educator received a teacher grant. |
| 1.1, 3.2 | 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) | Met |
| 1.3 | Increase the number of individuals engaged in each of the three associated categories: contacts (500 in aggregate), members (receive newsletter; 100 in aggregate), and participants (funded in some way; 50 in aggregate) | Exceeded |
| 1.1, 1.3 | Present at 5 informal science events or national education conferences | Exceeded |
| 1.3 | Communicate the deep biosphere in 5 general audience, non-scientific publications | Exceeded |

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| 2.1, 2.2 | Incorporate deep biosphere content in 3 C-DEBI and partner post-secondary programs (e.g., Global Environmental Microbiology (GEM) summer course, Community College Research Internship for Scientific Engagement (CC-RISE), Community College Cultivation Cohort (C4) REU, and the Agouron Institute International GeoBiology Course) | Exceeded |
| 3.1 | Award 10 individuals from varied institutions C-DEBI funding ranging from small research grants, research and travel exchanges, postdoctoral and graduate student fellowships, and E&O small grants | Met |
| 3.1, 3.2 | Support regular and varied methods for professional development exclusive to graduate students and postdoctoral researchers including weekly mailing list postings and an annual retreat | Met |
| 1.1, 1.2, 2.1, 2.2, 3.1, 3.2 | Assess measurable outcomes of program effectiveness using formative and summative evaluations of Very Good or Excellent (4 or 5 out of 5) conducted internally by C-DEBI education staff and by an external evaluator for all programs | Met (CC-RISE, GEM, Community College Instructor Workshops, Professional Development Workshop, etc.) |

**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 subseafloor biosphere researchers and on a broader scale, engage and retain STEM researchers.  Our future objectives are to:

1. Create ongoing outreach programs that include standards-based lesson plans and activities delivered to teachers, while providing outreach opportunities for graduate students and postdoctoral researchers.

2. Strengthen partnerships with community colleges by providing cutting edge research to faculty, promoting undergraduate courses and expanding summer research internship programs.

3. Expand 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. Use networking, existing organizations, social networking tools and local contacts to increase the scope of C-DEBI’s impact.

5. Promote calls for graduate student fellowships, travel grants, and postdoctoral researchers to attract the next generation of innovative scientists.

# IV. DATA MANAGEMENT AND KNOWLEDGE TRANSFER

## 1. Overall Data Management and Knowledge Transfer Goals and Objectives

C-DEBI facilitates 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 of all new discoveries, sensors, samplers, and platforms. This access has many avenues including but not limited to the distribution of information through teleconferences, our website, workshops, meetings, newsletters, presentations, technical documents, peer-reviewed publications, educational activities and outreach events. C-DEBI is also committed to mentoring students and scientists of all ages, including the exchange of personnel among laboratories and professional development.

The overarching objective of Data Management and Integration (DMI) and Knowledge Transfer (KT) to disseminate C-DEBI scientific discoveries and technical advances both to the scientific community and broader population has not changed; however, the emphasis is changing as the STC transitions from growth in Phase 1 to nurturing in Phase 2. As such, our DMI and KT goals include (1) implementing effective mechanisms to facilitate intellectual exchanges between institutions of various types, (2) maintaining worldwide access to C-DEBI data and information, (3) nurturing a new generation of C-DEBI researchers, (4) developing and make available targeted education, public outreach, and community interactions, and (5) promoting economic growth through technology development. Significant accomplishments and focused objectives of Center activities during the period of performance have been the development of a data portal, a concentrated effort to archive C-DEBI produced data in concert with BCO DMO, and focusing the dialogue for long-term, multi-disciplinary data storage for national programs.

## 2. Knowledge Transfer Activities and Organizations

C-DEBI knowledge transfer (KT) occurs on a near-constant basis with numerous organizations, most significantly with those highlighted in the [External Partnerships section V](#_V._EXTERNAL_PARTNERSHIPS_3). Here, we specifically call out KT activities that occurred during the reporting period and focused on overall goals one, two, and five above (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 KT (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, GEM, 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, 39 peer-reviewed journal articles, two theses, one book chapter, one EPO-related article were published. Each of these contributions is posted on our web page and introduced to the community in a monthly newsletter that reaches ~1000 individuals globally in addition to the journal and other modes of communicating these contributions. In addition, more than 110 presentations/posters were reported during the period of performance. These contributions were presented at numerous special sessions and workshops through large national and international meetings hosted by scientific organizations and partners (e.g., AGU, ISME, ASM, ISSM). Other, smaller C-DEBI leadership-hosted workshops and meetings also contributed to knowledge transfer. These meetings included two workshops (~15 people, each) that focused on summarizing and integrating C-DEBI activities in sedimented oceanic systems and in basaltic crust and 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.

As a Science and Technology Center, several new technological advances were made during the reporting period. These advances, which can take multiple years for development and implementation, fall with the categories of platforms, sensors, software, and laboratory technique. New developments include: (1) a full analysis for the development of CORK-Lite to fit a range of borehole structures; (2) initial sensor development for downhole laser-based calipers, low-temperature water samplers, and a mechanical mechanism for triggering a sampler in a high temperature (>60 °C) environment; (3) shallow water (<150 m) ROV and benthic observatory; (4) an optically stable dissolved oxygen sensor for hydrothermal systems; and (5) a data portal. Of these developments, one (mechanical mechanism for triggering a sampler in a high temperature (>60 °C) environment) has been submitted for a patent. It is anticipated that this patent will expand beyond academic users.

## 3. Data Management and Integration Activities and Organizations

# The C-DEBI Data Management and Integration (DMI) team is in place to ensure that C-DEBI data and products are archived, shared, and accessible for the long term. The data types and products covered by C-DEBI include a wide variety of geophysical, geological, geochemical, and biological information, in addition to education and outreach materials, technical documents, and samples. The overall DMI goal is to make sure that all data and information generated by STC-supported researchers as part of their C-DEBI projects are made publically available either following publication or within two (2) years of data generation (see details in our [Data Management Plan](http://www.darkenergybiosphere.org/internal/docs/C-DEBIDataManagementPlan_2015.pdf)). A second goal is to make certain that no STC researcher is limited by computational recourses (e.g., computers or tools). With the start of the second phase of C-DEBI, the DMI team will also take the responsibility to make sure the C-DEBI data are integrated in ways to allow larger more comprehensive analysis.

**a. Making Data Publically Available**

C-DEBI produces many kinds of products that need long term archiving. These include diverse data sets (biological, chemical, physical, and geological), samples, peer-reviewed publications, technological advances with associated engineering drawings and software, educational/outreach materials (such as K-12 and community college lesson plans relating to subseafloor science), and model parameters (e.g., inputs, grids, reaction rates). Biological products include, but are not limited to, molecular data, activity data (isotope abundance, community enzymatic, etc.), frozen samples, and living microbial strains, and post-processed molecular data (e.g., 16S rDNA and 16S rRNA sequences, single-cell genome, metagenome and metatranscriptome sequences). Non-biological data will include multi-beam maps, seismic reflection profiles, and thermal, chemical, and physical data from recovered samples of fluids, sediment, rocks, and experiments. Measurements also will be made *in situ* using borehole observatories, drilling platforms, cabled observatories, and coring facilities.

In 2015, we intensified our efforts to ensure that all post-embargo data were deposited in appropriate internationally accessible data repositories. The principal repository is the Biological and Chemical Oceanography Data Management Office (BCO-DMO). The C-DEBI DMI team has worked with BCO-DMO to make this location either the primary host of C-DEBI data or to have them provide stable links to data housed in other repositories; with linking to NCBI already available and soon similar links should be available to IODPdb and PRIDE. Products for which a suitable national repository does not exist, such as educational materials, outreach materials, and technical advances, have been posted directly in the C-DEBI Data Portal (C-DP). To the extent possible, all such products have also been described in peer-reviewed literature, to ensure public dissemination and long-term accessibility beyond C-DEBI. All C-DEBI intellectual products (publications, technical advances, software, education and outreach materials) are directly linkable through the C-DP. This portal provides direct electronic access to these products and also link to a broad range of other C-DEBI-relevant data.

We have made major progress in our mandate to deposit C-DEBI data in public repositories. Over the last year, the projects on the C-DEBI BCO-DMO webpage (<http://www.bco-dmo.org/program/554979>) have increased from one to eighteen. There are several others queued in the BCO-DMO quality check phase. The majority of the Small Grants programs that ended more than two years ago have deposited their required data in public repositories. Those who have not yet complied have been reminded to do so as soon as possible, and many have been in contact with BCO-DMO to complete this task. Of those that are not yet publicly available, ~15% are in the manuscript review process and ~29% are still generating their data. In both cases these PIs have been made aware of the requirement to deposit ultimately to BCO-DMO. Only 5% of these cases have failed to reply as to the status of their data. These PIs are currently unable to receive any additional C-DEBI resources until they are in compliance.



**b. Providing Computational Resources to C-DEBI Researchers (e.g., computing services and/or tools)**

In 2015, C-DEBI established and maintained a computing resource to accommodate data analysis on scales too large for laboratory computational resources, but too small (or poorly designed) for high powered computing centers. Currently, there are 9 C-DEBI researchers with access, provided on a rotating basis. These users are members of the larger C-DEBI community, and include graduate student and postdoctoral researchers from multiple labs and grants, not just the Investigators or Senior Scientists. The need for this service continues to grow, and we expect continued use in future years.

Beyond basic access to a maintained computer resource, several initiatives have been implemented to make sure C-DEBI researchers are not limited by any step in the bioinformatics process. One important aspect of this is the training of researchers on available tools. To this end, prior to the American Geological Union (AGU) Fall Meeting in December 2015, Dr. Benjamin Tully hosted a bioinformatics training session at Stanford University for 11 C-DEBI researchers. The attendees were also from the broader community, including faculty, postdoctoral researchers, and graduate students from many different laboratories. Information from that training session will be translated into various resources for general use by the scientific community, including YouTube tutorials and aggregated digital protocols at Protocols.io.

**c. Making C-DEBI Data Integrated to Allow Larger More Comprehensive Analysis**

An important aspect for Phase 2 will be to allow researchers to visualize and query all the C-DEBI data in new ways. To make this possible, we have started to make all the publicly available archived C-DEBI data discoverable via search indices exposed via the C-DEBI Data Portal (C-DP) user interface and RESTful APIs. Aggregated metadata will include archived datasets, derived metadata from column headers, and, to the extent of our computing capacity leveraging institutional and cloud resources, real-time access to copies of certain data types or derivative data (such as results of data mining or web scraping) for use in client software such as Python, R, JavaScript or other kernels providing data-analysis packages (see [https://jupyter.org/](https://jupyter.org/%22%20%5Ct%20%22_blank) for examples of browser-based, annotated and interactive code using publicly accessible data). The software used for the C-DP site, APIs and data workflow will themselves be made publicly available as GitHub repositories, gists and/or Docker containers of replica environments. Where sufficient metadata cannot be derived from existing resources, C-DEBI will reevaluate its target ontologies twice every year; once in the spring by the Investigators and Senior Scientists and once in the Fall by a larger component of the C-DEBI community at a session during the Annual meeting. This will be a major undertaking over the next few years, but we have begun the process.

Finally, we are continuing our efforts to make C-DEBI data available to the larger ocean sciences community. To this end, C-DEBI has worked to maintain a strong presence in the larger EarthCube community. Dr. Heidelberg is a member of the steering committee for the ECO-GEO RCN and, together with PI Amend and other C-DEBI members, participated in the EarthCube all-hands meeting this year. Heidelberg will also participate in the ECO-GEO town hall meeting at the Ocean Sciences meeting in February.

## 4. Performance with Respect to the Strategic Implementation Plan

Our data management and knowledge transfer goal is to implement effective mechanisms and pathways to facilitate the exchange and application of knowledge, expertise, physical resources, and novel methods and technologies within the STC and between the STC and the broader community. The overall data management plan is in place to 1) assure all data generated from the STC are deposited in publically accessible data repositories, 2) efficiently allow STC researchers tools and computational resources that allow them to efficiently perform data analysis, and 3) develop and maintain a data portal for visualization and hypothesis generation from the STC data.

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

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| **Metric** | **Status/Problems**  |
| Publish and promote scholarly activity via 10 publications | Met |
| Continue to develop research collaborations through networking at 2-3 interdisciplinary meetings and talks/posters/exhibition at 2-3 conferences | Met |
| Lead 3 C-DEBI-focused meetings or special sessions at national or international meetings | Met |
| Enhance, develop, or commercialize tools, analytical capabilities, software products, sensors and platforms (2 per year) | Met |

**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.

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| **Metric** | **Status/Problems**  |
| Continue to ensure all data generated through the STC are in stable public data repositories within 2 years of generation (or for graduate students upon defense of the dissertation or thesis) | Pending (details above) |
| Continue to develop web-based data portal bringing data together from various repositories for synthesis efforts | Met |
| Train researchers in new tools for data analysis by producing 3 webinars on data analysis tools per year and 2 small workshops for data analysis  | Pending as activities in Phase 2 develop; 1 workshop scheduled in December 2015 prior to AGU |
| Engage 20 new undergraduates to the fields of microbiology and oceanography and mentor 10 graduate students in C-DEBI fields | Met |
| Communicate with the public through non-scientific journals via social and journalistic media (5 significant contributions) | Met |

## 5. Plans for the Next Reporting Period

C-DEBI is planning long-range data management and 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.

# V. EXTERNAL PARTNERSHIPS

## 1. Overall External Partnerships Goals and Objectives

C-DEBI supports 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

During the first 5 years, C-DEBI developed and nurtured several very important external partnerships, both in its research and education efforts. Of particular note on the research side are long-standing and growing partnerships with the International Ocean Discovery Program (IODP), University-National Oceanographic Laboratory System (UNOLS), National Deep Submergence Facility (NDSF), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Deep Carbon Observatory (DCO), International Continental Drilling Program (ICDP), Schmidt Ocean Institute (SOI), NASA Astrobiology Institute (NAI), Los Alamos National Laboratory (LANL), and ExxonMobil. On the education side, we enter into our fourth year of partnership with the Agouron Institute to train graduate students, and we 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. We also expanded the CC-RISE program for community college students to conduct C-DEBI research to include UCSC and MBL. We recently secured NSF support through the Research Experiences for Undergraduates (REU) program to enlarge and diversify the CC-RISE program.

**IODP**

The IODP includes, as a primary focus area, 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 investigators. Other IODP expeditions have also provided important microbiological samples and data for C-DEBI investigators, including, but not limited to Expeditions 323 (Bering Sea Paleoceanography), 330 (Louisville Seamount Trail), 331 (Deep Hot Biosphere), 337 (Deep Coalbed Biosphere), 339 (Mediterranean Outflow), 347 (Baltic Sea Paleoenvironment), 353 (Indian Monsoon Rainfall), 357 (Atlantis Massif Serpentinization and Life), 365 (NanTroSEIZE Shallow Megasplay Long-Term Borehole Monitoring System), and 366 (Marina Convergent Margin). 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, with Senior Scientist Orcutt and Co-PI Wheat sailing as Co-Chief Scientists on Exp. 357 and Exp. 366, respectively.

**UNOLS and NDSF**

C-DEBI relies heavily on the UNOLS fleet of research vessels for expeditions, as well as the NDSF fleet of remotely operated vehicles (e.g., *Jason*), autonomous underwater vehicles (e.g., *Sentry*), the human occupied vehicle *Alvin*, particularly for CORK servicing activities and coring expeditions.

**JAMSTEC**

Members of C-DEBI collaborate closely with members of the Geomicrobiology Group (led by Fumio Inagaki) at the JAMSTEC-Kochi Institute for Core Sample Research. Members of C-DEBI have visited Kochi to learn new laboratory techniques and our JAMSTEC colleagues have provided independent lines of evidence for joint publications. Members of C-DEBI and JAMSTEC have also partnered on international expeditions and proposals for new expeditions.

**DCO**

The Sloan Foundation-funded DCO 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, infrastructure, and focused research initiatives (e.g., the Census of Deep Life (CoDL) and a project on rock-hosted communities). C-DEBI member Rick Colwell is the lead proponent of the CoDL and a member of the DCO Deep Life Steering Committee. C-DEBI Co-PI 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 and others are in the queue. DCO Deep Life Leadership and C-DEBI ExCom are in the planning stages for two joint workshops, one on existing and future culturing techniques for exploring uncultivated archaea, bacteria, viruses, and eukarya from the deep Earth, and one on integrating groundwater dating, hydrogeological flow, transport modeling, genomics, and evolutionary microbiology.

**ICDP**

C-DEBI is partnering with ICDP (and DCO) by supporting complementary aspects of proposed drill-based studies of the Oman ophiolite and its microbial communities. We also look forward to closer partnership with ICDP as it strengthens its program for study of subsurface life, for example through the planned drilling and exploration of subsurface life in the Death Valley rift zone.

**SOI**

SOI 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*. For example, Associate Director Huber has 2 cruises with SOI in 2016, and 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 NAI CAN-6 teams, with funding 2013-2017. This cross-disciplinary team, led by PI 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.

**LANL**

 C-DEBI (through the UCSC Hydrogeology group and colleagues in Applied Mathematics and Statistics) is collaborating with researchers at the Earth and Environmental Sciences Group at LANL to develop complex simulations of seafloor hydrothermal circulation. The numerical tools being developed and applied through this collaboration are facilitating greater complexity in representations of subseafloor fluid-heat-rock-microbial systems. The next steps for this effort include geologically realistic heterogeneity in formation properties and the initial stages of microbially mediated reactive transport in the volcanic crust.

**ExxonMobil Upstream**

C-DEBI (through Co-PI 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.

**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. For the past two years, C-DEBI has also partnered with the Monterey Area Research Institutions’ Network for Education (MARINE), a consortium of seven academic institutions. C-DEBI and MARINE have sponsored one-day professional development workshops for their respective graduate students and early career scientists. 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 site of our high school program, run by the USC SeaGrant program, and held at 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, CMOP) that enable us to train teachers at the K-16 levels.

## 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. Partnerships among individuals, institutes, organizations, and programs are the core of C-DEBI research and educational efforts. One of the strengths of these partnerships is the quality and broad appeal of publications. C-DEBI has a range of cross-disciplinary and cross-institutional collaborations that have transformed our view of subsurface microbial conditions, activity, and mechanisms within the hydrologic and geochemical context of fluid flow within the oceanic crust. Another strength of C-DEBI partnerships is the web of interaction of C-DEBI community within other organizations and programs and the joint efforts of these organization and programs in collaboration with C-DEBI to promote and facilitate synergetic research objectives. These partners also extend to education and diversity efforts, leading to a community of junior scientists that are engage in cross-disciplinary and cross-institutional training activities and 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.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems**  |
| Publish 5 (in aggregate) cross-disciplinary papers per each of the three research themes with support from calls for small research and travel grants to facilitate the interaction of dispersed Center researchers | Met |
| Submit 2 cross-disciplinary and cross-institutional proposals | Met |
| Support 2 interdisciplinary workshops or meetings in concert with other national programs  | Met |
| Fund 10 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 |
| Provide the funds that allow 3 student/researchers the opportunity 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:** Partnerships are developed with other fields, research organizations, industry, government, and foundations.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems**  |
| Build 10 (total) partnerships by networking at interdisciplinary meetings, developing industrial and governmental partners, and targeting partnerships and interactions for new applications of existing or budding technologies | Met |
| Develop documents and materials that highlight significant results through C-DEBI research, education, and diversity programs suited to specific organizations, foundations, and programs to form the basis of a dialogue between C-DEBI and that organization to further fiscal and research needs | Met |

## 4. Plans for the Next Reporting Period

C-DEBI has had long-standing partnerships with most of these external partners and the close collaborations are likely to continue at similar levels of commitment for the foreseeable future.

# VI. DIVERSITY

## 1. Overall Diversity Goals and Objectives

C-DEBI seeks totrain 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. In addition, C-DEBI’s research and education opportunities were advertised through the STC Tribal Network REU program and the Geoscience Alliance.

|  |  |  |
| --- | --- | --- |
| **C-DEBI Research and Administrative Participants** | **Women** | **Men** |
| Faculty (24) | 29% | 71% |
| Other Research Scientist (16) | 50% | 50% |
| Postdoctoral (24) | 58% | 42% |
| Graduate Student (24) | 58% | 42% |
| Undergraduate (63) | 65% | 35% |
| Other Participant (4) | 50% | 50% |
| Staff (4) | 100% | 0% |
| **Total (158)** |  **57%** |  **43%** |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **C-DEBI Research and Administrative Participants** | **White (all ethnicities)** | **White, Hispanic/ Latino** | **Native Hawaiian or Other Pacific Islander** | **Asian** | **African American** | **Native American** |
| Faculty (24) | 92% | 4% | 0% | 4% | 0% | 0% |
| Other Research Scientist (16) | 81% | 0% | 0% | 19% | 0% | 0% |
| Postdoctoral (24) | 88% | 8% | 0% | 4% | 0% | 0% |
| Graduate Student (24) | 88% | 13% | 0% | 0% | 0% | 0% |
| Undergraduate (63) | 27% | 19% | 3% | 8% | 41% | 2% |
| Other Participant (4) | 100% | 0% | 0% | 0% | 0% | 0% |
| Staff (4) | 75% | 0% | 0% | 25% | 0% | 0% |
| **Total (158)** | 64% | 11% | 1% | 7% | 16% | 1% |

C-DEBI continues to build on program successes of the past four years by expanding and evaluating four distinct projects targeting underrepresented minorities, women, and first generation and low-income students: the Global Environmental Microbiology (GEM) course, the Genomics and Geology Undergraduate Research Experience (GGURE), the USC Young Researchers Program, and the High School Marine Science Camp. These programs enrich the scientific skills of students through a combination of field-based research with professional development activities.

Our partnership with the USC Young Researchers Program provides 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. C-DEBI further reaches diverse student populations through various program partnerships including the USC SACNAS Chapter, SACNAS leadership, and the broader C-DEBI community through scientific talks and professional development.

# ► See more at the [Young Researchers Program webpage](http://youngresearchers.usc.edu/)

► See more at the [High School Marine Science Camp webpage](http://dornsife.usc.edu/uscseagrant/summer-science-programs/)

## 3. Impact of Programs or Activities on Enhancing Diversity at the Center

|  |  |  |  |
| --- | --- | --- | --- |
| **Program** | **Number of Participants** | **Diversity Objective** | **Measurement of Outcomes** |
| Global Environmental Microbiology (GEM) Summer Course | 16 (79 in 5 years) | Hands-on experience for 2- and 4-year undergraduate students in environmental microbiology | External evaluation,Retrospective survey,Longitudinal tracking |
| Young Researchers Program | 5 (22 in 5 years) | Research lab experience for high school students | Summary report |
| Marine Science Camp | 20 (79 in 4 years) | Hands-on exploration of oceanography for high school students | Summary report of survey |
| Genomics and Geology Undergraduate Research Experience (GGURE)  | 28 academic year | Academic year and summer research internship program for underrepresented undergraduate students at USC | External evaluation |

## 4. Performance with Respect to the Strategic Implementation Plan

Our diversity goal is to implement programs that introduce Center research and findings to members of underrepresented groups and strengthen the STEM pipeline. Through its academic programs, C-DEBI promotes inclusion and retention among underrepresented groups, including women and first-generation college students. With a strong base established to increase STEM diversity at all levels, we are developing and exporting distinctive, in-depth education and research experiences that encourage historically underserved students. These initiatives are targeted toward three primary sectors: 1) pre-college; 2) undergraduate and community college populations; and 3) early-career and established scientists. Diversity initiatives are incorporated into all education programming.

Our two main *objectives* are to:

1. increase the diversity in the C-DEBI community, especially underrepresented minorities, of C-DEBI graduate students and post-doctoral scholars; and
2. help minority undergraduate students (in community colleges and at USC), who are interested

in STEM majors, develop a path to a career in a STEM field.

|  |  |  |
| --- | --- | --- |
| **Objective** | **Metric** | **Status/Problems**  |
| 1 | Promote C-DEBI research opportunities to diverse audiences through partners (e.g., Institute for Broadening Participation) to increase the diversity of graduate students and postdoctorals across the center | Met |
| 2 | Develop or expand programs to attract underrepresented students into STEM fields | Met |
| 2 | Assess measurable outcomes of program effectiveness using formative and summative evaluations of Very Good or Excellent (4 or 5 out of 5) conducted internally by C-DEBI education staff and by an external evaluator for all programs | Met |
| 2 | Introduce C-DEBI science with appropriate resources and training to 1 institution and/or educator that primarily serves underrepresented groups | Met |

## 5. Plans for the Next Reporting Period

Our future goals are to:

1. 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
2. Continue to leverage support services and potential connections, organizations and institutional resources within partnering Universities to promote diversity
3. Actively promote all opportunities throughout the Center to underrepresented groups and recruit at all levels of Center activity
4. 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
5. Continue to leverage SACNAS involvement to promote and provide financial support to undergraduate and graduate students from C-DEBI to present research at the annual SACNAS conference
6. 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](http://www.darkenergybiosphere.org/internal/docs/C-DEBIOperationsManual_2015.pdf).



**Directorship**

The Center continues to be 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 Phase 1 major field 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 Senior Scientists (see Research section below) on C-DEBI research directions. ExCom generates calls for proposals and serves with the Senior Scientists as the review panel, with mechanisms to avoid conflict-of-interest.

ExCom consists of Phase 1’s five permanent members, and as part of the renewal management plan, we added two permanent members and two rotating members. The permanent members are Director and PI Jan Amend (USC), Associate Director and co-PI Julie Huber (MBL), co-PI Steven D’Hondt (URI), co-PI Andrew Fisher (UCSC), co-PI C. Geoffrey Wheat (U Alaska-Fairbanks), Data Management Director John Heidelberg (USC), and Education Director Stephanie Schroeder (USC). Heidelberg and Schroeder were added to ExCom to integrate our Data Management and Integration activities and our Education, Outreach, and Diversity programs with C-DEBI research. The rotating members consist of Senior Scientists (see Research management section below) added to complement the research expertise on ExCom and serving 15-month terms (currently Steven Finkel (USC) and Victoria Orphan (CalTech)). As previously reported, Phase 1 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 Dr. Rosalynn Sylvan, manages the Center’s day-to-day activities. They link to C-DEBI activities at the partner institutions and communicate with all participants worldwide. The Managing Director manages fiscal matters and grants administration and oversees the administrative staff. 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. The administrative staff are based at USC, and as of August, the Managing Director relocated to Texas A&M University as a Visiting Scholar at the International Ocean Discovery Program (IODP). The Managing Director’s transition to a remote position has been seamless with regular email and telecommunications in addition to the weekly administrative and ExCom meetings via videoconferencing.

**Research**

C-DEBI Phase 1 major field programs are led by members of ExCom, while cross-cutting research themes are led by ExCom and the Senior Scientists. Co-PI Fisher leads the Juan de Fuca Ridge field program, Co-PI D’Hondt leads the South Pacific Gyre field program, and Co-PI Wheat leads the North Pond and Dorado Outcrop field programs. As detailed in the [Research section II](#_II._RESEARCH_2) above, we have transitioned to three new research themes related to the renewal phase to encourage synthesis and integration across themes and sites. Five Senior Scientists were added last year 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 (USC), John Heidelberg (USC), Beth Orcutt (Bigelow Laboratory for Ocean Sciences), Victoria Orphan (California Institute of Technology), and Alfred Spormann (Stanford University).

**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 Education Director, Dr. Stephanie Schroeder, leads the professional development and mentoring efforts for undergraduate and graduate students, postdoctoral scholars, and K-12 teachers. She also serves as review chair of the small education and outreach grants proposals, and, in 2015, she was added to ExCom to integrate EOD activities with C-DEBI research. The Diversity Director (hiring in progress) will report to the Education Director and lead programs to entrain members of underrepresented groups into STEM fields with a special focus on microbiology, geochemistry, and oceanography. 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.

**External Advisory Board**

The External Advisory Board (EAB) provides an annual assessment of the science, education, mentoring, management, and functioning of C-DEBI to the Directorship. The four member committee of national and international leaders in both science and education includes Susan Humphris (WHOI), Doug Bartlett (Scripps), Rina Roy (American River College), and Judy Wall (University of Missouri). The EAB chair met with the C-DEBI leadership at the 2015 C-DEBI Annual Meeting to discuss future research and education directions and relevant EAB member recommendations. The EAB reports to the directorship in confidence, and their recommendations are communicated confidentially. The chair of the EAB will present her assessment at the Site Visit. Susan Humphris served as part of the EAB in Phase 1 and retains a historical perspective of C-DEBI with expertise in hydrothermal vent chemistry. New members are Doug Bartlett (Professor of Marine Microbial Genetics with expertise in deep-sea microbial diversity and ecology); Rina Roy (Dean of Science & Engineering at American River College, a community college located in Sacramento, CA); and Judy Wall (Professor of Biochemistry and Molecular Microbiology & Immunology with expertise in anaerobic metabolisms and experience with leading large programs). See their CVs in [[Appendix J](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-J-External-Advisory-Board-CVs.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-J-External-Advisory-Board-CVs.pdf). An additional member is being identified to represent a foundation perspective for Phase 3 of C-DEBI (i.e. the long-term future beyond the STC).

**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 (Education Officer of the IODP US Science Support Program at Lamont-Doherty Earth Observatory), 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](http://www.darkenergybiosphere.org/internal/ethics.html).

**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.

This fall, Rabin evaluated the effectiveness of the C-DEBI management team (ExCom, Administration, Education & Outreach Administration, and Data Management Team) on research support, scientific collaboration, education and outreach, and overall effectiveness for the period of 2014-2015. Both core affiliates (members with a leadership role or funded directly by C-DEBI) and those more loosely affiliated with the center responded, and 94% of the 150 respondents rated our overall effectiveness as “effective” or “highly effective” surpassing our target of 70%. This performance was a significantly higher rating (p<0.01) than our evaluation at 75% in 2013, indicating that the changes we implemented in response to survey comments and suggestions from the community have improved our effectiveness, especially with respect to transparency, proposal evaluation, bringing in new members, and stepping up our education and outreach and professional development efforts. We will continue to implement changes in response to the community’s comments and suggestions including extending the program’s reach and communications.  See [[Appendix K](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-K-Management-Effectiveness-Evaluation.pdf)](asdf) for the full report.

**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. Our Center 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 ~1000 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.

#  The C-DEBI website plays a number of important roles in Center communications, serving to provide an introduction to subseafloor biosphere research for the general public, as well as a repository for educational, scientific and professional resources. This year, the landing page design was updated to better convey the excitement of C-DEBI science, education, and outreach, along with video overviews created by USC’s communications division. Continued development of the website has focused on achieving a scalable backend to accommodate the Center’s diverse and growing array of data products, written materials, participant activities and community opportunities. Our approach to these ends consists of: 1) improving ease of data entry via integrations with end-user-friendly tools; 2) providing data enrichment via harvesting pipelines with community-relevant websites and services; 3) improved user experience and site performance with modern front end development libraries and scalable backend data services; 4) ease of deployment and cost-effective access to computing resources via Docker; and 5) software-friendly access to C-DEBI website and data portal data via RESTful APIs for consumption by iPython notebooks, visualization dashboards, R packages, etc. Our target date for the next major website release is the 2016 Site Visit, with regular feature improvements ongoing.

**4. 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.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Hold weekly administration meetings as well as weekly ExCom meetings and an annual ExCom face-to-face retreat to enable clear and effective management of the Center | Met |
| 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” | Exceeded |
| Invite the evaluation of Center research, education, diversity, and knowledge transfer management 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 | Met; Phase 2 EAB membership being finalized |
| Update the C-DEBI Operations Manual 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 | Met |

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

|  |  |
| --- | --- |
| **Metric** | **Status/Problems**  |
| Regularly update the comprehensive website at www.darkenergybiosphere.org with research and education portals and resources | Met |
| 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 | Met |
| Continue to improve the private login site for internal documents and community reporting | Met |
| Solicit nominations for the next season of the videoconferenced Networked Speaker seminar series to present early career scientist research to the C-DEBI community | Met |
| 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.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Organize 5-7 C-DEBI-specific opportunities for collaboration and training and entrain new membership (e.g., Center-wide Annual Meetings, Research Workshops, and Exchange Grants) | Met |
| Support 4-6 research and professional development opportunities specifically for graduate students and postdoctorals (e.g., workshops at Annual Meetings, professional development webinars, and fellowships and networking activities in Research and Education sections above) | Met |

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

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Require 100% of participants complete ethics training within these standards | Met |
| 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) | Met |

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

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Secure $3M in aggregate (beyond initial STC funding) in support of C-DEBI activities | Met |

## 5. 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. See also Data Management and Integration in [section IV](#_IV._DATA_MANAGEMENT_1) above).

# VIII. CENTER-WIDE OUTPUTS AND ISSUES

## 1. Center Publications

In the current reporting period, the C-DEBI community produced 58 publications, including 48 peer-reviewed journal articles ([[Appendix L](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-L-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)). The spreadsheet indicates graduate and postdoctoral authors, contributing C-DEBI funding, major program, site and theme association.

## 2. Conference Presentations and Other

##### Center participants reported 131 oral or poster presentations at venues including the 2015 Goldschmidt Conference in Prague, the 2015 AGU Fall Meeting, and Gordon Research Conferences ([[Appendix L](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-L-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)).

## 3. Honors, Awards and Grants

##### C-DEBI participants reported receiving 26 (with another 6 pending) honors, awards and grants during the reporting year related to their C-DEBI funding ([[Appendix L](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-L-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)).

## 4. Placement of Graduated Students and Postdoctorals

##### Twenty-three C-DEBI undergraduate, graduate students, postdoctoral scholars and early-career scientists obtained degrees or placement during the current reporting year ([[Appendix L](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-L-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)). C-DEBI funding contributing to the degrees or placement is identified.

## 5. Outputs of Knowledge Transfer Activities

The C-DEBI community developed 12 technologies in the current year including platforms, sensors, software, and E&O products ([[Appendix L](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-L-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)). See also [Section III: Education](#_III._EDUCATION) and [Section IV: Data Management & Knowledge Transfer](#_IV._KNOWLEDGE_TRANSFER).

## 6. All Participants

Of the 246 individuals reported as being involved with Center activities, 152 are classified as “participants” (per NSF: individuals who have spent over 160 hours on Center activities), while 94 are “affiliates,” reported 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 L](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-L-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx) for details.

## 7. Institutional Partners

C-DEBI has identified 93 participating institutions categorized per NSF reporting requirements. Types are determined based on the activities of its participants as follows:

Graduate student: *education, research*

Postdoctoral or researcher: *research*

Outreach or professional development: *education*

Program targets diverse groups: *diversity, education*

Participant worked on new tools, software, methods or products: *knowledge transfer*

Participant plays an advisory or managerial role in the Center: *all types*

Whether the institution has “participated” less or more than 160 hours is likewise determined by its affiliated participants. See [[Appendix L](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-L-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx) for details. See also the [External Partnerships section V](#_V._EXTERNAL_PARTNERSHIPS_4) above.

## 8. Summary Table for Internal NSF Reporting Purposes

|  |  |
| --- | --- |
| **Number of participating institutions (all academic institutions that participate in activities at the Center)** | 61 |
| **Number of institutional partners (total number of non-academic participants, including industry, states, and other federal agencies, at the Center)** | 32 |
| **Total leveraged support (funding for the Center from all sources other than NSF-STC)** | $321,713 |
| **Number of participants excluding affiliates (total number of people who utilize center facilities; not just persons directly supported by NSF)** | 152 |

## 9. Media Publicity

##### Twenty-nine media publicity items have been identified, including press releases, news articles, videos, an Al Jazeera America TV episode, and a TBS ‘King of the Nerds’ runner-up ([[Appendix L](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-L-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)).

**10. Distributable Media**

##### Our [current brochure](http://www.darkenergybiosphere.org/internal/docs/C-DEBIbrochure2015dec.pdf) 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

C-DEBI regularly and consistently engages the international community in the majority of its activities with individual and institutional partnerships as described throughout this report. Of particular note are research expeditions, especially IODP cruises, where multi-national participation is generally mandated, and C-DEBI-led conference sessions and workshops, where scientists from Germany, Japan, China, Great Britain, France, and other countries are commonly invited. All other outputs, impacts, or influences related to the Center’s progress and achievement in 2015 have been captured in other sections of this report.

# X. BUDGET

## 1. Current Award Year and Unobligated Funds

The Center’s current award year budget (4/1/15 – 3/31/16) is $5,099,762 including the final 6 month period of Phase 1 ($2,499,762 4/1/15-9/30/15), the initial 6 month period of Phase 2 ($2,500,000 10/1/15-3/31/16) and an educational supplement of $100,000. Of the current award year budget, 26% supports lead investigators including the PI, Co-PIs and Senior Scientists (see figure below). Indirect costs at USC consist of 20% of the budget. Over half the budget serves the greater C-DEBI community with support for grants and fellowships, education and diversity programs, community meetings and activities, data management, and the general administrative operations based at USC. Our grants program typically includes support for small seed research grants of $50,000-80,000 per year, and we are currently accepting proposals to begin in the next award year. So far this year we have awarded 6 special research grants of ~$100,000 each, 1 travel exchange grant, 5 postdoctoral fellowships of $62,500 each and 4 graduate fellowships of $33,000 each (see details in the [Research section II.2.f](#_f._Other_Projects) above and [[Appendix B](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-B-Active-Grants-and-Fellowships.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-B-Active-Grants-and-Fellowships.pdf)). Our education and diversity programs target all audiences from teachers, K-12, undergraduates/community college students, graduates, postdoctorals, and the general public. Community meetings and activities include the C-DEBI Annual Meeting and C-DEBI Site Review. Administrative support includes salary and fringe benefits for the USC staff, work study students, travel and other operating costs. Education and diversity and data management staff are included in their respective categories.



As of October 31, 2015, we have expensed 73% of the total award of $5,099,762 for the current award year including the final 6 month period of Phase 1 (4/1/15-9/30/15) and the initial 6 month period of Phase 2 (10/1/15-3/31/16; see [[Appendix M](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-M-Current-Award-Year-Budget.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-J-Current-Award-Year-Budget.pdf)). These expenditures of $3,731,124 consist of expenses posted in the USC ledger as of 10/31/15, however do not include liens/obligations (e.g., subcontracts) and known pending expenses (e.g., USC salaries). At the time of this financial report, the subcontracts to renewal science leads (co-PIs and Senior Scientists) were not yet finalized due to the renewal funds having just been distributed to USC, which consists of a large portion of the total award (14%). The bulk of the remaining funds will support operating costs (e.g., the upcoming Site Visit) and the next round of grants to be reviewed in early 2015.

The discrepancy between what has been expensed (and reported to NSF by USC Sponsored Projects Accounting) and what is reported in [[Appendix M](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-M-Current-Award-Year-Budget.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-J-Current-Award-Year-Budget.pdf) is the inclusion of our committed expenses. For example, a large portion of our budget is in our small research grants and fellowships which are awarded as 1-2 year subcontracts or satellite accounts, and we report as committed expenses of ~$50K per award. However, the expenses reported by USC's SPA only include the individual invoices paid by USC which are incrementally billed/paid up to the entire award of ~$50K over the 1-2 year award period. What we report above carefully accounts for these types of commitments that may not be completely billed and paid for some period of time. This amount has increased each year because we continue to award grants and fellowships and have only begun to start closing the initial awards out with final invoicing at the same rate. See [[Appendix N](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-N-USC-Account-Status.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-K-Management-Effectiveness-Evaluation.pdf) for a statement of our accounts in the USC Financial Accounting System.

## 2. Requested Award Year

In the next award period (4/1/16 – 3/31/17), we will continue to support the Co-PI and Senior Scientist research groups, central administration at USC, data management, meetings and activities, education and diversity programs and grants and fellowships (see figure below and [[Appendix O](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-O-Requested-Award-Year-Budget.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-L-Requested-Award-Year-Budget.pdf)).

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## 3. Center Support from All Sources

In addition to NSF core funds including an educational supplement this year, the center received $321,713 directly from USC in the form of institutional returns on indirect costs this year, and will received $276,600 annually in Phase 2 (see table below). In the current award year and the requested award year, the USC Institutional Support funded additional Center activities including research in Director Jan Amend’s research group, GEM Summer Course instructors (an additional 0.5 month of summer salary each), and additional C-DEBI community meetings and activities. Remaining funds are used at the Director’s discretion to support important Center projects and to position C-DEBI closer to renewal success. See details of non-monetary institutional commitment in [Appendix P](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-P-Institutional-Commitment.pdf).

|  |  |  |
| --- | --- | --- |
| **Center Support** | **Current Award Year** | **Requested Award Year** |
| NSF-STC Core Funds | $5,099,762 | $5,000,000 |
| USC Institutional Support | $321,713 | $276,600 |
| TOTAL | $5,421,475 | $5,276,600 |

**4. Additional PI Support From All Sources**

Additional levels of support not included above have been awarded to Center PIs from federal and state agencies, industry, university, and private foundations and organizations (see table below).

|  |  |  |
| --- | --- | --- |
| **Additional Support** | **Current Award Year** | **Requested Award Year** |
| NSF | $993,784 | $831,559 |
| Other Federal Agencies (EPA, NASA) | $2,295,059 | $2,474,114 |
| State Government (California) | $33,750 | $28,202 |
| Industry | $87,847 | $0 |
| University | $120,327 | $108,984 |
| Private Foundations(DCO/Sloan, etc.) | $52,257;DCO Census of Deep Life sequencing | $26,000 |
| TOTAL | $3,583,025 | $3,468,859 |