

Sulfate reduction energetics at Main Endeavor grotto chimney from samples collected on RV Atlantis (AT18-08) during Jason II dives in the Juan de Fuca Ridge from July to August 2011

Website: <https://www.bco-dmo.org/dataset/661659>

Data Type: Cruise Results

Version: 1

Version Date: 2016-10-14

Project

- » [Characterization of Microbial Transformations in Basement Fluids, from Genes to Geochemical Cycling](#) (North Pond Microbes)
- » [Characterizing the distribution and rates of microbial sulfate reduction at Middle Valley hydrothermal vents](#) (Middle Valley Vents)

Programs

- » [Center for Dark Energy Biosphere Investigations](#) (C-DEBI)
- » [International Ocean Discovery Program](#) (IODP)
- » [Center for Dark Energy Biosphere Investigations](#) (C-DEBI)

Contributors	Affiliation	Role
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Abstract

Sulfate reduction energetics at Main Endeavor grotto chimney from samples collected on RV Atlantis (AT18-08) during Jason II dives in the Juan de Fuca Ridge from July to August 2011

Table of Contents

- [Coverage](#)
- [Dataset Description](#)
 - [Acquisition Description](#)
 - [Processing Description](#)
- [Related Publications](#)
- [Parameters](#)
- [Instruments](#)
- [Deployments](#)
- [Project Information](#)
- [Program Information](#)
- [Funding](#)

Coverage

Spatial Extent: Lat:47.95 Lon:-129.1

Temporal Extent: 2011 - 2011

Dataset Description

The effects of key environmental variables (temperature, pH, H₂S, SO₄²⁻, DOC) on sulfate reduction energetics in material recovered from a hydrothermal flange from the Grotto edifice in the Main Endeavor Field, Juan de Fuca Ridge. Sulfate reduction was measured in batch reactions across a range of physico-chemical conditions. Temperature and pH were the strongest stimuli, and maximum sulfate reduction rates were observed at 50 degrees celsius and pH 6.

Information for this dataset was derived from single massive piece of hydrothermal deposit (approximately ~100 kg in weight) that was recovered from a flange on the Grotto vent (47.949, -129.098) at a depth of 2188.3 m (Dive J2-575, AT-18-08, R/V Atlantis) and brought up to the surface in the basket of the ROV Jason II.

Methodology for this dataset is from: Frank et al., 2015

Acquisition Description

Tables and Figures referenced in the acquisition description are found in the paper Frank et al., 2015

For each independent treatment, aliquots of 7.5 mL flange slurry (approx. 29 g wet weight and 20 g dry weight) were transferred into Balch tubes in an anaerobic chamber, and supplemented with 15 mL of sterile artificial seawater media designed to mimic the geochemical conditions within a hydrothermal flange (400 mM NaCl, 25 mM KCl, 30 mM CaCl₂, 2.3 mM NaHCO₃, 14 mM NaSO₄²⁻, 1 mM H₂S, and 50 uM dissolved organic carbon - consisting of equimolar proportions 10 uM of pyruvate, citrate, formate, acetate, lactate) under a pure nitrogen headspace.

Concentrations of sulfide, sulfate and dissolved organic carbon (DOC) were varied independently to investigate concentration dependent effects on the rates of SR. The range of experimental conditions tested was determined from previously published concentration profiles of aqueous species modeled as functions of temperature and position within the Grotto vent structure (Tivey, 2004). Concentrations were varied by orders of magnitude within the modeled ranges to simulate conditions representative of different mixing regimes between seawater and vent fluid (Table 1). The range of DOC (which we approximate as a mix of pyruvate, citrate, formate, acetate, lactate – most of which have been identified to varying degrees within vent fluid and are known carbon sources for heterotrophic SR in culture) concentrations tested were based on the average DOC concentrations measured within diffuse fluids at the Main Endeavor Field (Lang et al., 2006; Lang et al., 2010). Hydrogen sulfide was present as H₂S (pK_a in seawater of 6.60) across all the conditions tested (Amend & Shock, 2001). Incubations were carried out at pH 4 (to simulate the pH of end-member Grotto vent fluid and the average calculated pH of mixed fluids in highly reduced zones within the flange; Tivey 2004) as well as pH 6 (representative of the calculated pH in fluid mixing zones; Tivey 2004). All the results are presented and discussed in the context of the initial measured media conditions.

Processing Description

Tables and Figures referenced in the processing description are found in the paper Frank et al., 2015

Potential energy yields of the different metabolisms available in the incubations depend on

temperature and fluid compositions. To quantify the energy yield from heterotrophic sulfate reduction (Table 2) in each incubation values of overall Gibbs energy (ΔG_r) were calculated according to:

$$\Delta G_r = \Delta G_r^0 + RT \ln Q$$

where ΔG_r^0 is the standard Gibbs energy of reaction at *in situ* temperature and pressure conditions, R is the gas constant, T is the temperature (Kelvin), and Q is the activity product, defined as

$$Q = \prod a_i^{v_i}$$

where a_i represents the activity of the i th species and v_i is the stoichiometric reaction coefficient, which is positive for products and negative for reactants. Values of ΔG_r^0 were calculated at 1 bar and incubation temperatures using the geochemical software package SUPCRT92 (Johnson *et al.*, 1992) and additional thermodynamic data from (Shock, 1995). Activities of aqueous species were calculated using the geochemical speciation program EQ3 (Wolery, 1992) based on the media composition described in section 2.2 and Table 1, with additional data from previously published work (Shock, 1995; Shock & Koretsky, 1993). For concentrations equal to zero, a value of 10^{-13} mol/kg was used as input. Resulting aqueous activities were used to calculate values of ΔG_r normalized for the number of electrons transferred in the redox for the reactions in Table 2. These reflect the metabolic energy available at the start of each incubation experiment for the complete oxidation of each organic acid, metabolisms that are documented among known sulfate reducers (Amend and Shock, 2001). Furthermore, to calculate the energy density in each incubation (as in Amend *et al.*, 2011), it was assumed that the amended organic acids were the limiting reactant for all experiments when sulfate concentrations were in excess of 1 mM; otherwise sulfate was assumed to be limiting. While some sulfate reducers are known to produce carboxylic acid and alcohol intermediates, incomplete oxidation reactions were not considered here, as the goal of these calculations was to generate a broad understanding of sulfate reduction energetics, and not the metabolic potential for a particular species. Such an approach is common when comparing microbial metabolisms independent of species-specific pathways (e.g. Amend *et al.*, 2004; Rogers & Amend, 2006; Skoog *et al.*, 2007), although it should be noted that incomplete oxidation (fermentation) generally yields much less energy than complete oxidation (Rogers & Amend, 2006; Skoog *et al.*, 2007).

To account for potential interactions between chimney-derived trace metals and amended sulfide, the saturation states of sulfide minerals were calculated as part of the initial fluid

speciation. Using reported concentrations of relevant trace metals (Fe, Zn, Cu, etc.) in end-member Grotto hydrothermal fluid (Butterfield *et al.*, 1994), maximum aqueous activities of trace metals were calculated with the EQ3 geochemical speciation program (EQ3/6 1998; EQ3NR 1998). Several sulfide minerals commonly found in hydrothermal chimneys (e.g. pyrite, chalcocite, sphalerite) were supersaturated under incubation conditions, particularly for incubations with high concentrations of amended sulfide. The irreversible abiotic precipitation of mineral sulfides has the potential to draw down aqueous sulfide concentrations and impact sulfate reductions rates. Therefore, the geochemical reaction path program EQ6 (EQ3/6 1998; EQ6 1998) was used to constrain fluid compositions to equilibrium with these mineral phases. Using the single point model in EQ6, the Gibbs energy of the system was allowed to reach local minima by mineral precipitation, however redox reactions among carbon and sulfur species was suppressed with a custom thermodynamic database. The resulting fluid compositions were used to calculate metabolic reaction energetics as well as to evaluate the potential effects of metal speciation on sulfate reduction rates.

BCO-DMO Data Processing Notes:

- reformatted column names to comply with BCO-DMO standards
- filled in all blank cells with nd
- removed spaces and replaced with underscores

[[table of contents](#) | [back to top](#)]

Related Publications

Frank, K. L., Rogers, K. L., Rogers, D. R., Johnston, D. T., & Girguis, P. R. (2015). Key Factors Influencing Rates of Heterotrophic Sulfate Reduction in Active Seafloor Hydrothermal Massive Sulfide Deposits. *Frontiers in Microbiology*, 6. doi:[10.3389/fmicb.2015.01449](https://doi.org/10.3389/fmicb.2015.01449)

[[table of contents](#) | [back to top](#)]

Parameters

Parameter	Description	Units
experiment_num	PI issued experiment ID number	unitless
sulfide	Independently varied concentration of sulfide	molar (M)

sulfate	Independently varied concentration of sulfate	millimoles (mM)
DOC	Independently varied dissolved oxygen concentration	micromoles (uM)
citrate	Citrate concentration which made up DOC	molar (M)
formate	Formate concentration which made up DOC	molar (M)
pyruvate	Pyruvate concentration which made up DOC	molar (M)
acetate	Acetate concentration which made up DOC	molar (M)
lactate	Lactate concentration which made up DOC	molar (M)
bicarbonate	Concentration of bicarbonate which made up artificial seawater mix	millimoles (mM)
K	Concentration of K which made up artificial seawater mix	molar (M)
Ca	Concentration of Ca which made up artificial seawater mix	molar (M)
Na	Concentration of Na which made up artificial seawater mix	molar (M)
Cl	Concentration of Cl which made up artificial seawater mix	molar (M)
pH	pH of media added to incubations; Incubations were carried out at either pH 4 or 6; 4: simulates the pH of end-member Grotto vent fluid and the average calculated pH of mixed fluids in highly reduced zones within flange (Tivey 2004). 6: represents the calculated pH in fluid mixing zones (Tivey 2004).	pH
temperature	Temperatures at which samples were incubated anaerobically for 1 3 or 7 days. 4 C: ambient seawater; 50 C: thermophilic; 90 C: hyperthermophilic.	celsius (C)
sulfateRed_formate	(DeltaGr KJ/mol e-) of formate calculated at pH 6 and 50 deg C for heterotrophic sulfate reduction via organic acids	DeltaGr KJ/mol e-
sulfateRed_acetate	(DeltaGr KJ/mol e-) of acetate calculated at pH 6 and 50 deg C for heterotrophic sulfate reduction via organic acids	DeltaGr KJ/mol e-

sulfateRed_pyruvate	(DeltaGr KJ/mol e-) of pyruvate calculated at pH 6 and 50 deg C for heterotrophic sulfate reduction via organic acids	DeltaGr KJ/mol e-
sulfateRed_lactate	(DeltaGr KJ/mol e-) of lactate calculated at pH 6 and 50 deg C for heterotrophic sulfate reduction via organic acids	DeltaGr KJ/mol e-
sulfateRed_citrate	(DeltaGr KJ/mol e-) of citrate calculated at pH 6 and 50 deg C for heterotrophic sulfate reduction via organic acids	DeltaGr KJ/mol e-
c_limiting_totalEnergy	Carbon limiting total energy available in bottle for sulfate reduction	joules (J)
S_limiting_totalEnergy	Sulfate limiting total energy available in bottle for sulfate reduction	joules (J)
total_energy	Total energy available for sulfate reduction	joules (J)
lat	Latitude	decimal degrees
lon	Longitude	decimal degrees

[[table of contents](#) | [back to top](#)]

Instruments

Dataset-specific Instrument Name	Incubator
Generic Instrument Name	In-situ incubator
Dataset-specific Description	Used aboard ship and in lab
Generic Instrument Description	A device on shipboard or in the laboratory that holds water samples under controlled conditions of temperature and possibly illumination.

Dataset-specific Instrument Name	pH sensor
Generic Instrument Name	pH Sensor
Dataset-specific Description	pH sensor
Generic Instrument Description	General term for an instrument that measures the pH or how acidic or basic a solution is.

Dataset-specific Instrument Name	DO sensor
Generic Instrument Name	Dissolved Oxygen Sensor
Dataset-specific Description	DOC was measured
Generic Instrument Description	An electronic device that measures the proportion of oxygen (O ₂) in the gas or liquid being analyzed

[[table of contents](#) | [back to top](#)]

Deployments

AT18-08

Website	https://www.bco-dmo.org/deployment/568087
Platform	R/V Atlantis
Report	http://dmoserv3.whoi.edu/data_docs/C-DEBI/cruise_reports/AT18-08_nemo11-cruise-report.pdf
Start Date	2011-07-19
End Date	2011-08-01
Description	Data expected from C-DEBI investigator, Julie Huber. Additional cruise information and original data are available from the NSF R2R data catalog.

AT18-08_Jason_Dives

Website	https://www.bco-dmo.org/deployment/661574
Platform	R/V Atlantis
Start Date	2011-07-21
End Date	2011-07-31

[[table of contents](#) | [back to top](#)]

Project Information

Characterization of Microbial Transformations in Basement Fluids, from Genes to Geochemical Cycling (North Pond Microbes)

Coverage: North Pond, mid-Atlantic Ridge

Description from NSF award abstract: Current estimates suggest that the volume of ocean crust capable of sustaining life is comparable in magnitude to that of the oceans. To date, there is little understanding of the composition or functional capacity of microbial communities in the sub-seafloor, or their influence on the chemistry of the oceans and subsequent consequences for global biogeochemical cycles. This project focuses on understanding the relationship between microbial communities and fluid chemistry in young crustal fluids that are

responsible for the transport of energy, nutrients, and organisms in the crust. Specifically, the PIs will couple microbial activity measurements, including autotrophic carbon, nitrogen and sulfur metabolisms as well as mineral oxide reduction, with quantitative assessments of functional gene expression and geochemical transformations in basement fluids. Through a comprehensive suite of in situ and shipboard analyses, this research will yield cross-disciplinary advances in our understanding of the microbial ecology and geochemistry of the sub-seafloor biosphere. The focus of the effort is at North Pond, an isolated sediment pond located on ridge flank oceanic crust 7-8 million years old on the western side of the Mid-Atlantic Ridge. North Pond is currently the target for drilling on IODP expedition 336, during which it will be instrumented with three sub-seafloor basement observatories. The project will leverage this opportunity for targeted and distinct sampling at North Pond on two German-US research cruises to accomplish three main objectives: 1. to determine if different basement fluid horizons across North Pond host distinct microbial communities and chemical milieus and the degree to which they change over a two-year post-drilling period. 2. to quantify the extent of autotrophic metabolism via microbially-mediated transformations in carbon, nitrogen, and sulfur species in basement fluids at North Pond. 3. to determine the extent of suspended particulate mineral oxides in basement fluids at North Pond and to characterize their role as oxidants for fluid-hosted microbial communities. Specific outcomes include quantitative assessments of microbial activity and gene expression as well as geochemical transformations. The program builds on the integrative research goals for North Pond and will provide important data for guiding the development of that and future deep biosphere research programs. Results will increase understanding of microbial life and chemistry in young oceanic crust as well as provide new insights into controls on the distribution and activity of marine microbial communities throughout the world's oceans. There are no data about microbial communities in ubiquitous cold, oceanic crust, the emphasis of the proposed work. This is an interdisciplinary project at the interface of microbial ecology, chemistry, and deep-sea oceanography with direct links to international and national research and educational organizations.

Characterizing the distribution and rates of microbial sulfate reduction at Middle Valley hydrothermal vents (Middle Valley Vents)

Coverage: Middle Valley vent field along the Juan de Fuca Ridge

This project characterizes rates of microbially mediated sulfate reduction from three distinct hydrothermal vents in the Middle Valley vent field along the Juan de Fuca Ridge, as well as assessments of bacterial and archaeal diversity, estimates of total biomass and the abundance of functional genes related to sulfate reduction, and in situ geochemistry. Maximum rates of sulfate reduction occurred at 90°C in all three deposits. Pyrosequencing

and functional gene abundance data reveal differences in both biomass and community composition among sites, including differences in the abundance of known sulfate reducing bacteria. The abundance of sequences for Thermodesulfovibro-like organisms and higher sulfate reduction rates at elevated temperatures, suggests that Thermodesulfovibro-like organisms may play a role in sulfate reduction in warmer environments. The rates of sulfate reduction observed suggest that - within anaerobic niches of hydrothermal deposits - heterotrophic sulfate reduction may be quite common and might contribute substantially to secondary productivity, underscoring the potential role of this process in both sulfur and carbon cycling at vents. This project was funded, in part, by a C-DEBI Graduate Student Fellowship.

[[table of contents](#) | [back to top](#)]

Program Information

Center for Dark Energy Biosphere Investigations (C-DEBI)

Website: <http://www.darkenergybiosphere.org>

Coverage: Global

The mission of the Center for Dark Energy Biosphere Investigations (C-DEBI) is to explore life beneath the seafloor and make transformative discoveries that advance science, benefit society, and inspire people of all ages and origins. C-DEBI provides a framework for a large, multi-disciplinary group of scientists to pursue fundamental questions about life deep in the sub-surface environment of Earth. The fundamental science questions of C-DEBI involve exploration and discovery, uncovering the processes that constrain the sub-surface biosphere below the oceans, and implications to the Earth system. What type of life exists in this deep biosphere, how much, and how is it distributed and dispersed? What are the physical-chemical conditions that promote or limit life? What are the important oxidation-reduction processes and are they unique or important to humankind? How does this biosphere influence global energy and material cycles, particularly the carbon cycle? Finally, can we discern how such life evolved in geological settings beneath the ocean floor, and how this might relate to ideas about the origin of life on our planet? C-DEBI's scientific goals are pursued with a combination of approaches: (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 seafloor 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. Note: Katrina Edwards was a former PI of C-DEBI; James Cowen is a former co-PI. Data Management: C-DEBI is committed to ensuring all the data generated are publically available and deposited in a data repository for long-term storage as stated in their Data Management Plan (PDF) and in compliance with the NSF Ocean Sciences Sample and Data Policy. The data types and products resulting from C-DEBI-supported research include a wide variety of geophysical, geological, geochemical, and biological information, in addition to education and outreach materials, technical documents, and samples. All data and information generated by C-DEBI-supported research projects are required to be made publically available either following publication of research results or within two (2) years of data generation. To ensure preservation and dissemination of the diverse data-types generated, C-DEBI researchers are working with BCO-DMO Data Managers make data publicly available online. The partnership with BCO-DMO helps ensure that the C-DEBI data are discoverable and available for reuse. Some C-DEBI data is better served by specialized repositories (NCBI's GenBank for sequence data, for example) and, in those cases, BCO-DMO provides dataset documentation (metadata) that includes links to those external repositories.

International Ocean Discovery Program (IODP)

Website: <http://www.iodp.org/index.php>

Coverage: Global

The International Ocean Discovery Program (IODP) is an international marine research collaboration that explores Earth's history and dynamics using ocean-going research platforms to recover data recorded in seafloor sediments and rocks and to monitor seafloor environments. IODP depends on facilities funded by three platform providers with financial contributions from five additional partner agencies. Together, these entities represent 26 nations whose scientists are selected to staff IODP research expeditions conducted throughout the world's oceans. IODP expeditions are developed from hypothesis-driven science proposals aligned with the program's science plan Illuminating Earth's Past, Present, and Future. The science plan identifies 14 challenge questions in the four areas of climate change, deep life, planetary dynamics, and geohazards. IODP's three platform providers include: The U.S. National Science Foundation (NSF) Japan's Ministry of Education, Culture,

Sports, Science and Technology (MEXT) The European Consortium for Ocean Research Drilling (ECORD) More information on IODP, including the Science Plan and Policies/Procedures, can be found on their website at <http://www.iodp.org/program-documents>.

Center for Dark Energy Biosphere Investigations (C-DEBI)

Website: <http://www.darkenergybiosphere.org>

Coverage: Global

The mission of the Center for Dark Energy Biosphere Investigations (C-DEBI) is to explore life beneath the seafloor and make transformative discoveries that advance science, benefit society, and inspire people of all ages and origins. C-DEBI provides a framework for a large, multi-disciplinary group of scientists to pursue fundamental questions about life deep in the sub-surface environment of Earth. The fundamental science questions of C-DEBI involve exploration and discovery, uncovering the processes that constrain the sub-surface biosphere below the oceans, and implications to the Earth system. What type of life exists in this deep biosphere, how much, and how is it distributed and dispersed? What are the physical-chemical conditions that promote or limit life? What are the important oxidation-reduction processes and are they unique or important to humankind? How does this biosphere influence global energy and material cycles, particularly the carbon cycle? Finally, can we discern how such life evolved in geological settings beneath the ocean floor, and how this might relate to ideas about the origin of life on our planet? C-DEBI's scientific goals are pursued with a combination of approaches: (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. Note: Katrina Edwards was a former PI of C-DEBI; James Cowen is a former co-PI. Data Management: C-DEBI is committed to ensuring all the data generated are publically available and deposited in a data repository for long-term storage as stated in their Data Management Plan (PDF) and in compliance with the NSF Ocean Sciences Sample and Data Policy. The data types and products resulting from C-DEBI-supported research include a wide variety of geophysical,

geological, geochemical, and biological information, in addition to education and outreach materials, technical documents, and samples. All data and information generated by C-DEBI-supported research projects are required to be made publically available either following publication of research results or within two (2) years of data generation. To ensure preservation and dissemination of the diverse data-types generated, C-DEBI researchers are working with BCO-DMO Data Managers make data publicly available online. The partnership with BCO-DMO helps ensure that the C-DEBI data are discoverable and available for reuse. Some C-DEBI data is better served by specialized repositories (NCBI's GenBank for sequence data, for example) and, in those cases, BCO-DMO provides dataset documentation (metadata) that includes links to those external repositories.

[[table of contents](#) | [back to top](#)]

Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-1061934
NSF Division of Ocean Sciences (NSF OCE)	OCE-0838107
NASA Astrobiology Science & Technology for Exploring Planets (NASA-ASTEP)	NNX09AB78G
NASA Astrobiology Science & Technology for Exploring Planets (NASA-ASTEP)	NNX07AV51G

[[table of contents](#) | [back to top](#)]