2010 Ridge 2000 Community Meeting

Integrating Observations, Analyses and Models of Oceanic Spreading Center Processes

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Portland, OR, USA

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A Working Group Approach to Integration and Synthesis of Mid-Ocean Ridge Studies.

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Introduction and Background

The overarching goal of the Ridge 2000 program is to answer key questions pertaining to fundamental processes that control biological, chemical and geological phenomena at oceanic spreading centers using observational, experimental and modeling data derived from the past few decades of research on mid-ocean ridges. The program has completed many successful field campaigns and shore-based research projects, resulting in the publication of a large volume of scientific papers spanning many subjects. The task the program now faces is how to synthesize the accumulated knowledge from the past ~8 years of field and laboratory data, and decades of allied research, into widely accessible published products. This synthesis is expected to yield new insights into oceanic spreading center processes, impact multiple related research fields, and pave the way for new scientific directions that will extend our knowledge of fundamental earth-ocean processes.

The work of Ridge 2000 (R2K) is multi-disciplinary. Answering some of the broader research questions posed in the R2K science plan requires a collaborative, cross-disciplinary approach that has proved difficult thus far to initiate on a community wide scale. One difficulty has been the delay of key experiments at some sites, with the result being that key data sets have only recently been collected and published, or are in the final stages of publication. Nevertheless, there is a general consensus that R2K has contributed substantively to both the ocean sciences in general and in a focused way to multidisciplinary studies at ridges, both through the scale of the effort and through the development of new technologies required to study seafloor processes. However, the successful completion of the synthesis of R2K scientific results both within and across the key study areas (aka Integrated Study Sites) is required to demonstrate that R2K has fully reached it stated program goals. We expect that many in the program will see the results of this effort as both a very satisfying culmination to decades of MOR research and a roadmap to future questions and research on the general topic.

The Working Group Approach

This white paper describes how a team-work approach to the synthesis of R2K scientific results, using topical/thematic working groups with foci that address a subset of the overall program goals, can be used to advance integration and synthesis goals of the R2K program. This method has proved successful in multiple other research venues.

The idea in a nutshell is to use topical and ISS focused working groups to formulate ideas, stimulate discussion, and synthesize results on program-relevant topics into high profile publications. This effort uses a systems approach, focusing the groups toward different ridge processes and/or structural elements of ridge environments. It differs from the largely geographic (ISS and cross-ISS) focus R2K has used for the past 3 years of community meetings.

Working groups will be formed in conjunction with a research community-wide meeting with group topics loosely defined by the meeting organizers. Groups will work together before, during, and following the meeting to choose topics and datasets within their focus area that are ready for this synthesis effort, work toward integrating and synthesizing knowledge on them, and write and publish synthesis papers. Large groups may choose to work as several subgroups if this best meets their needs. In other research communities, the most successful implementations of the working group approach suggest that the R2K groups will be maximally productive if they operate over a one to two year period, and if members of multiple disciplines are committed to communicate, learn from each other, and develop a shared-vision for their objectives and published products. Thus, the products of the groups will be developed over time, with the hope that additional collaborations are born from this process and that new ideas spring from the synthesis effort. While we hope that some of the ideas and papers developed at the community meeting can be published in the following year, we fully realize that in some cases this process may take longer.

Interactions within each working group:
Each group will likely comprise approximately 10 participants of different backgrounds, perspectives and seniority levels. Groups should therefore have a high degree of flexibility in terms of how they interact and schedule their interactions, and how they divide up tasks to individual members. But, group interactions should nevertheless be guided by functional and ethical protocols established by the architects of this effort before the groups meet. Groups should have multiple tools and venues for interaction at their disposal, including telecommunications, virtual meeting, on-line forums and in-person meeting options.

Working Group Leaders:
To be most effective, each group should have several leaders who are generally knowledgeable about the topic, open-minded, and willing to commit to the effort. These leaders will jumpstart discussions, facilitate the integration and synthesis process-before, during and after the meeting, and referee the interactions within the group. They need not be the leaders of paper writing efforts that arise from the group, but certainly can choose that role if they wish.

Integration and Synthesis Leaders:
The overall effort described here needs a few higher level leaders that will devise the structure and operating protocols of the working groups and the community meeting, interact with group leaders, mediate sticking points that might arise within groups, and generally steer the overall process.

The Community Meeting:
The role of the community meeting is to bring all the groups together face-to-face after they have had a chance to begin interactions, to give them the opportunity to have focused, multi-day discussions on the work at hand, set schedules for producing their group products, and to learn about the work of other groups, including topics they are addressing and successful collaboration modes. The community meeting is a means to an end, rather than a specific, fixed time frame to accomplish the synthesis effort. The key point is that the meeting can serve as an impetus for the community to embark on the path that will lead to fully capitalizing on R2K research to date, by synthesizing and integrating information to achieve a more complete knowledge of MOR processes.

Community Commitment to Achieving R2K Program Goals
To be successful, large-scale scientific research programs such as R2K require vision, innovation in conceptualization and execution of its studies, community participation at all levels, and funding agency support over the term of the program. In practice the ‘net-worth’ of a large-scale research program is measured by its productivity, both in terms of scientific results and in terms of impacts on the field(s) of study. R2K has in many ways been the vanguard of ‘multidisciplinary’ ocean-earth studies and has demonstrated how researchers with a broad array of research tools, methods and practices can work together on shared research goals. Researchers involved in the program have a strong desire to understand the ‘interconnectedness’ of MOR phenomena as epitomized by the ‘Mantle to Microbe’ iconic statement that ushered in R2K nearly 10 years ago. The process will be challenging, but we believe the community is ready for an organized effort like the one described here

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Larval transport along the East Pacific Rise

Diane Adams
National Institutes of Health

Larval dispersal is an essential component to determining both the biogeography and adaptive capabilities of hydrothermal vent invertebrates. R2K-related projects studying larval dispersal along the 9N segment of the East Pacific Rise (EPR) have combined modeling and physical and biological observations to investigate mechanisms of larval transport and estimate population connectivity. Observations occurred both before and after the 2006 eruption, providing a unique opportunity to determine the role of larval supply in controlling the successional sequence at vents. Pre-eruption, established vents received the bulk of their larvae locally, within a few kilometers (Adams and Mullineaux 2008).

The 2006 eruption eradicated local larval sources providing a natural clearance experiment which confirmed that the larval supply was predominantly local at established vents (Mullineaux et al 2010). It also revealed that distant propagules can establish dominance after the removal of the established communities. Thus, there is a temporal variation in population connectivity or 'openness' – with established vents being closed and nascent and disturbed vents being open. The variation in population connectivity is adaptive to the unique characteristics of hydrothermal vents – specifically here the isolated and ephemeral nature. Retention of propagules prevents excessive wastage of reproductive energy and allows for rapid establishment of abundant populations. Change to predominantly open populations once disturbed allows for rapid initial establishment and/or replenishment of populations. Larval dispersal, and reproductive strategies (Bayer et al 2010, Tyler et al 2009), could be part of a new synthesis of macrofaunal and megafaunal adaptations to the hydrothermal vent environment.

The post-eruption data sets could also allow us to begin to address, through integration with chemical data sets, "What controls the species composition and succession at hydrothermal vents?" - abiotic vs biotic controls; more specifically - environment (and physiological tolerances) vs. larval supply.

Due to the large number of microbiologists in this group and the recent progress in investigating microbial succession, a comparison of the factors driving microbial succession to macrofaunal succession could reveal general rules of succession at vents.

Oceanographic events also can episodically change the proportion of local vs distant propagules. Mesoscale eddies were observed to transport larvae away from local vents (Adams et al in prep). Multiple modeling methods suggest that these eddies could transport the larvae hundreds of kilometers between vent fields along the EPR (Adams and Flierl 2010, Adams et al in prep). This mechanism for larval transport could also significantly contribute to the exchange of heat, chemicals, and other organic material between the hydrothermal vents and the larger ocean. Consideration of transport to the larger ocean could enhance models of lithosphere – ocean exchange.

The new empirical estimates of larval transport provide testable hypotheses about population connectivity along the EPR. Previous empirical estimates where seemingly at odds with genetic estimates of population connectivity. The new estimates reconcile this apparent contradiction by observing temporal variation in connectivity. New population genetic techniques and analyses have the potential to provide an indirect and independent estimate of connectivity.

Linking Biogeochemistry to Microbial Activity and Distribution in a Sedimented Hydrothermal Vent Ecosystem

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Marine sediments harbor microbial communities that mediate globally relevant biogeochemical cycles. Sedimented hydrothermal vents are unique ecosystems as both high organic load from overlying sediments and high temperature fluids influence the microbial communities associated with these ecosystems. Methane and other short-chain alkanes (C2 - C4 hydrocarbons) can serve as key sources of metabolic energy for survival in such environments. Recent integrative studies focused on the anaerobic oxidation of methane (AOM) have elucidated much about the identity (Hinrichs et al., 1999), functional potential (Kruger et al., 2003; Hallam et al., 2004), and ecophysiology (Girguis et al., 2003, 2005) of the marine microbial consortia that mediate this widespread process. Furthermore, C2 - C4 hydrocarbons are a major component of the utilizable carbon pool in deep sea sediments worldwide, including hydrothermal vent systems. Recent studies have also demonstrated that sulfate-reducing microbes isolated from the deep sea can survive solely on propane (C3) and butane (C4) (Kniemeyer et al., 2007).

However, the influence of environmental and geochemical gradients on these microbial communities remains largely uncharacterized. Middle Valley is a sediment-filled rift valley that represents one of the most geochemically distinct environments at Juan de Fuca Ridge. Geochemical characterization of these sediments has revealed high levels of Fe, Cr, and As in these hydrothermally altered sediments with surface layers exhibiting high amounts of Mn, Cu, and Zn as a result of diagenetic processes. A recent study indicated that there is a greater flexibility of different electron acceptors that can be utilized for AOM than previously assumed, such as manganese and iron oxides (Beal et al., 2009). We are utilizing an integrative biogeochemical approach to investigate how the availability of methane and C2 - C4 hydrocarbons affects the metabolic activity of microbial populations in Middle Valley. We are combining quantitative molecular and geochemical techniques including laboratory experiments, in situ studies, and thermodynamic modeling to determine the degree to which the anaerobic oxidation of methane and C2 - C4 hydrocarbons supports these communities.

Contributions to Integration and Synthesis: Preliminary results from the lab of Dr. Peter Girguis at Harvard show that methane and C2 - C4 hydrocarbons are metabolized to varying degrees in sediments from Middle Valley. Recent data from our group also demonstrates the first evidence to date constraining AOM at temperatures >50°C and indicating that temperature limits drive the community composition of putative methanotrophs mediating AOM (M.M. Adams and S.D. Wankel, in preparation). However, a better understanding of metabolic processes in such anaerobic, high temperature environments is necessary to determine the extent to which these communities use hydrocarbons for energy generation. Working with the larger community to develop such integrative approaches and synthesize a more complete picture of hydrocarbon metabolism in sedimented hydrothermal vents will shed light on how vent biogeochemistry is linked to the microbial communities associated with sediments in Middle Valley.

Research Opportunities and Educational Outreach Activities for Non-Traditional Groups

Nancy H. Akerman[1], Allison Beauregard Schwartz[2], Julie A. Huber[1]

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Deep-sea research is expensive and difficult to pursue, and therefore is mainly only accessible to those involved with grants for such research. However, exciting images of deep-sea vents and their associated life forms can spark interest in many audiences. Providing opportunities to non-traditional groups, such as students from non-research institutions like community colleges, to be involved in deep-sea research and to meet scientists engaged in such research can be exciting and rewarding for all involved.

An example of a unique educational outreach effort was conducted this summer, when Dr. Julie Huber of the Marine Biological Laboratory hosted two summer undergraduate interns chosen from Northwest Florida State College in Fort Walton, FL (NWFSC, formerly Okaloosa-Walton Community College). This collaboration grew out of the 2008 Ridge 2000 Distinguished Lecturer Series, during which Dr. Huber was hosted at NWFSC by Dr. Allison Beauregard Schwartz. As part of the visit, Huber met with undergraduates from Beauregard Schwartz's Oceanography class, followed by an evening public lecture to ~350 people, representing students, faculty, and members of the Niceville community. Both Huber and Beauregard Schwartz felt the visit was an extremely valuable experience, and led to the inclusion of Beauregard Schwartz and the internship/curriculum program into Huber's NSF research grant to Biological Oceanography. The internship experience allowed for one-on-one mentoring opportunities in Huber's laboratory between research institute personnel and community college students, a group that is traditionally far removed from research science. The interns worked in our laboratory for 10 weeks, learning skills that included anaerobic culturing, phase contrast and fluorescence microscopy, DNA extraction, molecular cloning, PCR, and DNA sequencing and analysis. They each isolated and analyzed a microorganism originally collected from deep-sea hydrothermal vents on a research cruise to NW Rota. They concluded their experience by giving a talk on their summer research to other summer students, and they and Huber will also give talks about their research experience at their home college. In addition, Huber and Beauregard Schwartz are developing curricula on environmental microbiology and deep-sea science, two topics not commonly covered in community college courses, which will be taught in several colleges. Next summer, Huber's lab will sponsor two more students from NWFSC, and the summer students may even have the opportunity to participate in a research cruise. This internship and teaching partnership can serve as a model program for collaborations between other education-focused institutes and research institutes.

At the meeting, I look forward to sharing my experiences from the MBL-NWFSC collaboration, discussing ideas for bringing deep-sea science to a wider and less traditional audience, getting involved in the outreach programs that are currently running, and organizing more outreach opportunities.

Microbial ecology of deep sea hydrothermal plumes

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Hydrothermal plumes are zones where the reaction of hydrothermal vent fluids with sea water serves as an important habitat for chemolithotrophic microbial communities. Hydrothermal plumes are composed of two distinct parts, namely: 1) The initial rising plume which is comprised of vent fluids that mix with the sea water and are carried upwards in a plume. 2) The laterally dispersing neutrally buoyant plume. Thus, hydrothermal plumes serve as a natural environmental geochemical gradient to support microbes of various physiologies.
Most sampling efforts in the past focused on the neutrally buoyant plume, however, recent advancements in sampling (Breier et al. 2009) have allowed us to take a full suite of samples through the hydrothermal plume. Accordingly, we collected a set of 80 microbial samples in addition to samples for geochemical and mineralogical analyses across the hydrothermal plumes of five vent fields at the Eastern Lau Spreading Center(ELSC) in 2009.
For my Ph. D thesis, I have proposed to study the microbial ecology of hydrothermal vent systems at the ELSC. Some of the key questions that I am investigating during the course of my research are: 1)What are the compositions of microbial communities in hydrothermal plumes and where are they derived from? 2) How do microbial communities evolve through the hydrothermal plume with co-evolving geochemistry? 3) How do microbes mediate geochemical reactions in the rising and neutrally buoyant plumes?
My approach involves the use of metagenomics and pyrosequencing of 16s rRNA genetags to address the above questions and also correlate findings with associated geochemistry and mineralogy.
Contribution to synthesis
Although there have been a number of recent advances in recent years in the microbiology of hydrothermal plumes (e.g. Huber et al. 2007, Dick et al. 2009, Dick et al. 2010), major gaps still exist in our knowledge of microbial communities. Considering how microbial processes may be critical in determining the fate of hydrothermal effluents and their influence on global ocean chemistry, it is important that we understand the nature and composition of microbes inhabiting hydrothermal plumes. At the meeting, I will present preliminary results of tag–sequencing across five vent fields of Lau Basin. Taking into account the interdisciplinary nature of this research and the interactions with other microbiologists, geochemists and mineralogists, it is my goal to work with the larger community to integrate our efforts in synthesizing the microbiology, geochemistry and mineralogy of hydrothermal plumes.
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How are event plume fluids generated?

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Since the discovery of "event (mega) plumes" in 1986 on the Juan de Fuca Ridge, three additional ridge-crest eruptions on the JdF and Gorda Ridges have produced six separate event plumes with volumes ranging from ~15-120 km3. In addition, five additional plumes with some characteristics similar to event plumes have been observed worldwide, at spreading rates from 11 (Gakkel Ridge) to 140 (Manus Basin) mm/yr. In 2008, an eruption on the Northeast Lau Spreading Center created a unique set of multiple event plumes, smaller but chemically similar to all previous event plumes.

The uniformity of event plumes and their unfailing association with seafloor eruptions testifies that the tectonic/volcanic processes that accompany eruptions include fundamental physical and chemical processes that are not yet understood. Candidate hypotheses must satisfy five principal characteristics of event plumes: (1) rapid (<~1 d) formation of plumes, (2) unique and consistent chemistry (low ratios of 3He and Mn to heat), (3) the occasional production of multiple event plumes, (4) lava-seawater interaction (basalt shards, high H2), and (5) lava and plume heat content correlated (~2:1, respectively) over two orders of magnitude.

Current hypotheses are divided between those that require the sudden release of hydrothermal fluids from the crust or melt, and those that require the rapid transfer of heat from cooling lava to seawater. Hypotheses requiring a combination of these processes are also possible, and perhaps likely. The fluid-release hypotheses require (1) large volumes (as much as ~0.1 km3) of hydrothermal fluid stored along, or created within, a few linear km of ridge crest, (2) fluids with a worldwide chemical uniformity greater than, and distinct from, black smoker discharge, and (3) very high bulk permeability in both the discharge and recharge zones. Lava-cooling hypotheses require (1) transfer of heat from lava to seawater much faster than possible by simple conductive cooling of a solid flow, and (2) consistently uniform (as ratioed to heat) extraction of 3He and Mn from both pillow and sheet lava flows.

An improved understanding of events that create new ocean crust will require the integration of existing field observations of events (perhaps reinterpreted) with new geological, chemical, and hydrodynamic models. Some specific issues include crustal permeability, storage of hot fluids in the crust, the role of magmatic volatiles, and lava-seawater interaction during an eruption.

Geochemical Diversity of Near-Ridge Seamounts: Insights into Oceanic Magmatic Processes and Sources

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Geochemical studies of lavas erupted at near-ridge seamounts may provide an opportunity to better understand the composition of shallow mantle beneath spreading ridges and some of the melting processes that occur to form oceanic crust. While on-axis samples generally reflect homogenization of melts within the axial magma lens, seamount lavas bypass this process, providing a window into the diversity of melts produced in the melting column. By studying near-ridge seamount lavas, we hope to better understand the effects of mantle heterogeneity and melt generation/transport on the geochemistry of lavas erupted in these settings.

We have analyzed lavas from the Lamont Seamount chain adjacent to the EPR (~9° N), the Vance Seamount Chain adjacent to the JdF ridge (~45° N), as well as several individual seamounts/cones located off the JdF ridge. Lavas from these seamounts have incompatible trace element patterns varying from very depleted to moderately enriched (found at the oldest, most distant Vance seamounts) relative to typical mid-ocean ridge basalts (MORB). Overall, the Vance and Lamont seamount lavas are more primitive and diverse than associated ridge samples. These variations can be explained by different degrees of melting and mixing of multiple sources The significant variations in incompatible trace element and isotopic compositions that are somewhat correlated suggest that the mantle underneath the seamounts is heterogeneous on a small scale. Our results support a "veined mantle" model for the Northeastern Pacific mantle and the mantle underneath the EPR.

We are particularly interested in how dissolution-precipitation reactions that are hypothesized to occur during melt transport in the mantle might relate to the diverse trace element compositions found in these seamount chains. We are working on trace element modeling using MELTS and IRIDIUM to see if the creation of dunite conduits through dissolution of CPX and precipitation of olivine in depleted mantle lherzolite can explain the trends seen in these seamounts. By better understanding the processes that are occurring to form these seamounts, we hope to be able to compare them to lavas produced at the ridge, in order to better understand the ridge system as a whole, both on- and off-axis.

Questions and discussion ideas:

Do similar off-axis (vs. back arc) seamounts exist near the Lau spreading center?

There is only minimal evidence for any hydrothermal activity on these seamounts. Is this a consequence of non-steady state magma chambers and melt production. Is the lack of observed hydrothermalism reflected in the chemistry of the lavas (low Cl?).

What is the geophysical evidence for and constraints on the locations and extents of axial and off-axis melting? What mechanism can cause these often linear chains to form? How is the "excess" heat generated to cause melting if the mantle has been previously depleted at the ridge crest? What does the significant volume of these features tell us about the melting process?

Recent studies on slow spread ridges (and ophiolites) indicate there is a significant amount of melt rock interaction in the upper mantle and lower crust (including the formation of dunite veins). What evidence (for and against) is there for this at the ISS sites?

Larval abundance and dispersal at deep-sea hydrothermal vents in the southern Mariana Trough: comparison to Ridge 2000 EPR ISS

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Despite three decades of research on deep-sea hydrothermal vents, the processes that govern larval dispersal, settlement, and recruitment to these discrete and sometimes ephemeral habitats remain poorly understood, even at well-studied sites. To understand larval dispersal to/from vents, we are presented with many challenges which include:
- difficulties in quantitative sampling of the plankton,
- lack of physical oceanographic measurements, and
- little to no information on larval behavior.

All of these challenges are compounded by the difficulties in sampling over long-enough time scales and fine-enough temporal resolution to understand a process that has temporal variability caused by the physical environment and by reproductive biology (also not well-studied for vent-endemic fauna).

Larval dispersal drives population connectivity on short (i.e., generational) time scales and ultimately the biogeography and evolution of species on very long time scales. We have studied larval dispersal at the Ridge 2000 East Pacific Rise (EPR) Integrated Studies Site (e.g., Mullineaux et al. 2005, Mullineaux et al. 2010), including the recent LADDER project (http://www.whoi.edu/projects/LADDER) which incorporated physical oceanography, regional circulation modeling, and particle-tracking models (e.g., McGillicuddy et al. 2010).

In September 2010 we will collect larvae in a different biogeographic province on the other side of the Pacific, in the southern Mariana Trough (for more information on biogeographic provinces, please see Van Dover et al. 2002 and Bachraty et al. 2009). We will deploy large-volume plankton pumps at approximately 3000-m depth at Snail (also called South Backarc), Archaean, and Pika, three of the Vents (Volcanic) Unit sites in the U.S. Marianas Trench Marine National Monument. These vents near the back-arc spreading center are being studied as part of the Japanese multi-disciplinary program TAIGA (Trans-crustal Advection and In-situ biogeochemical proceses of Global sub-sea floor Aquifer). We will deploy a current meter near the Snail site (on-axis) for preliminary estimates of passive larval transport on the time scale of the cruise. We also plan to conduct experiments at 1 atm and in pressure chambers to estimate swimming and/or sinking velocities of vent larvae, important for adding behavioral information to models of larval dispersal.

We will compare the larval abundances, diversity, and preliminary estimates of dispersal between the back-arc (Mariana Trough) and the mid-ocean ridge (EPR) vents to address the question posed in the Ridge 2000 Science Plan: "Q5. What are the forces and linkages that determine the structure and extent of the hydrothermal biosphere?" Although our studies are only at small spatial scales (over several km, on single ridge segments), and the comparison between EPR and the Mariana back-arc vents can only be made at the short time scale of a single research cruise, we hope that by conducting such studies at different sites in different tectonic settings, that a more general understanding of larval dispersal between vents can be developed.

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Examining Links among Symbiont Physiology, Holobiont Distribution and Physicochemical Habitats at Hydrothermal Vents

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Deep-sea hydrothermal vents are dominated by symbiotic associations (Cavanaugh et al. 2006), which represent the majority of biomass and, in aggregate, are often more productive than rainforests and kelp beds (Girguis and Childress 2006). Invertebrates from three phyla host chemoautotrophic bacteria, primarily γ-Proteobacteria, which harness energy from chemical oxidation to fix inorganic carbon (Cavanaugh et al. 2006). These symbionts are often the primary source of nutrition for the host species. While most are thought to be autotrophic sulfide oxidizers, little is known about the particular pathways, intermediates, and alternate substrates that are part of their chemolithotrophic metabolism. Moreover, few connections have been made between the metabolic capacity of chemosynthetic symbionts and the specific chemical regimes occupied by their hosts.

Given the importance of the Proteobacteria to these partnerships (as the primary source of nutrition), physiological differences among the symbionts of chemosynthetic vent fauna may have profound effects on the distribution of the holobionts. Indirect evidence for this comes from previous studies that suggest that certain host animals associate with specific physicochemical regimes at vents (Le Bris et al. 2003, Le Bris et al. 2006, Luther III et al. 2001, Matabos et al. 2008, Moore et al. 2009, Podowski et al. 2009, Waite et al. 2008), though the fundamental cause for this zonation remains almost entirely unexplored (Colaco et al. 2002). While the role of symbiont physiology has been studied to some extent in other symbioses-dominated ecosystems (e.g. its role in the zonation of cnidarians(Thornhill et al. 2008, Verde and McCloskey 2007)), it has never been systematically examined or characterized among the chemoautotrophic symbioses. In order to better understand faunal distribution in vent ecosystems, it is crucial to investigate the underlying differences in symbiont physiology that may play a role in the niche differentiation of holobionts within vent habitats.

Gastropods of the genus Alviniconcha are found at hydrothermal vent fields in the Western Pacific and Indian Ocean and have been reported to host intracellular γ- or ε-Proteobacterial endosymbionts individual(Suzuki et al. 2005a, Suzuki et al. 2005b, Suzuki et al. 2006, Urakawa et al. 2005) . An extensive sampling effort from a recent expedition to the Eastern Lau Spreading Center (ELSC) has revealed that Alviniconcha with symbionts of both types are found at vent fields along the ridge and that the relative abundance of individuals with each type at a vent field relates to the geology and geochemistry of that site. It is likely that the metabolic differences between the γ- and ε-Proteobacterial endosymbionts are influencing this distribution pattern. This work suggests that endosymbiont metabolism plays an important role in the distribution of host animals at hydrothermal vents and should be investigated in other chemosynthetic associations. It is imperative that we bring together studies of the physicochemical habitat (e.g. geology and geochemistry) and holobiont distribution with studies targeting symbiont physiology. Ultimately, this will facilitate a better understanding of the role of the symbiont in the ecology and evolution of many vent invertebrates.

Tidal-scale variations in plumes and their implications for estimating vent-scale heat fluxes

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The patterns of bending and variations in entrainment rates observed over a 24 hour time series of acoustic images of the plume rising from the north tower of Grotto Vent, which was reported in Rona et al. (2006), suggest a strong influence of the tidal cycle on plumes but also significant complexity. This complexity comes in several ways: 1) The bending of the plumes is stronger in the southern direction. 2) The timing of the bending of the plumes does not seem to be in phase with the tidal cycle. 3) The relationship of plume strength, plume bending and entrainment rate is not entirely consistent.

While more data is needed to verify the above interpretation (see Rona's white paper on acquiring data), the context and implications for the behavior of the rising plume merits consideration: Grotto Vent, like many of the vents on the Endeavour segment of the Juan de Fuca Ridge, is a large (10+ m tall) mound, which has many places discharging very hot fluids, including black smokers, flanges, beehives, and white smokers as well as diffuse fluids emanating from every surface. Furthermore, Grotto Vent is actually 2 separate mounds in close proximity: the taller but narrower north tower, which has the strongest black smokers based on backscatter intensity in acoustic images, and shorter but wider and roughly peanut shaped south mound, which seems to mostly diffuse flow with a few black smokers. The direction of bending may influence which sources merge into the main plume(s), which would change the rise rate and the impact of the tidal currents on entrainment and bending leading to the observed complexity.

In contrast, on the EPR, there are single plumes discharging from isolated black smokers, or at least that's what many discussions imply. In the only acoustic imaging data taken on the EPR (Rona et al., 1991; Bemis et al., 2002), we saw what started as two very separate black smoker plumes (4m separation at base) merge at 18 mab. So even here, relationships between source, tide and plume are complex.

An effective conceptual model relating the behavior of the rising plume to its source(s) needs to account for a) the size of the area that contributes heat to plume, b) the multiplicity of heat sources, c) the non-linear addition of momentum when plumes merge (which results in an increase in the rise rate greater than might be anticipated), and d) the response of the plume to changes in tidal current speed and direction.

I propose a new conceptual model: First, the vent or mound is a diffuser plate (a grate with flow and heat supplied more or less uniformly from below), where it is anticipated that heat comes from an area rather than a point source. Second, when multiple mounds are sufficiently nearby each other, their plumes will interact when tidal currents bring them in close proximity but not necessarily otherwise. Thus interactions are variable over time as well as space. Neither of these aspects makes the calculation of heat flux for a vent field easier -- more data is needed to judge variability in time and to account for interactions. Everything we've learned within the scope of Ridge 2000 suggests that our models and methods of heat flux estimation are too simplistic (see B Lavelle's comments and animation on the R2K 2010 Community meeting wiki site).

The integration of other data and observations should help turn this qualitative model into a quantitative model. And in any case, it should provide a context or stimulus for discussion of how to integrate data and models that aim to estimate heat and chemical fluxes. The merging affects may also have implications for models of how event plumes form.

The effect of microorganisms on chemical speciation within the hydrothermal plume

TWG - Biogeochemical processes – Interaction between life and minerals

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Over the history of hydrothermal research, geochemists have reported the chemistry of the deep-sea plume environment to be inorganically dominated, following abiotic oxidation kinetics and thermodynamically favorable products (Field and Sherrell, 2000; German and Von Damm, 2004). Meanwhile, biologists have detected elevated cell concentrations within the plume and have more recently reported the presence of both auto- and heterotrophic microorganisms (Sunamura et al., 2004; Lam et al., 2004; Dick and Bradley, 2010; German et al., 2010; Sylvan et al., In prep). The biological utilization of reduced chemical species adds an additional component to both the kinetic and thermodynamic controls on the chemistry within the plume.

For example, oxidation could either become slower or faster under microbiological controls than predicted from kinetic calculations. Statham et al. (2005) demonstrated that the Fe oxidation rates in samples collected from a hydrothermal plume in the Indian Ocean were slower than predicted, whereas in the Guaymas basin oxidation rates of Mn were elevated within the plume (Dick et al., 2009). More recently, Fe(II) was found co-located with organic carbon within sediment trap samples collected at 9°50'N East Pacific Rise, even though Fe(II) is kinetically unstable in oxic conditions (Toner et al., 2009). Toner et al. (2009) determined that the organic carbon was composed of exopolymeric material, i.e. organic substances excreted from microbial species. Organic complexation of inorganic minerals within the plume can lead to stabilization of intermediate phases, which would otherwise crystallize and form more complex mineral structures (Bennett et al., 2008). This has the potential to impact the chemical budgets of the ocean on a global scale (Tagliabue et al., 2010).

These recent studies highlight the importance of collaborative research between microbiologists and geochemists within the plume environment and more directed research to address the impact of microbiology on chemical speciation. Even though the elevated concentration of constituents within the plume compared to the open ocean should enable us to exploit with ease current techniques, we must address issues associated with the deep-sea environment. The time delay between sampling and sample processing has produced artifacts in our results because of changes in the chemical speciation and biological communities over time (Bennett et al., 2009). On the flip side, the elevated concentrations within the plume make in-situ sensing devices a potential solution.

NEPTUNE Canada installations at Endeavour Ridge

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NEPTUNE Canada

NEPTUNE Canada is operating a regional cabled ocean observatory across the northern Juan de Fuca Plate in the northeastern Pacific. Installation of the first suite of instruments and connectivity equipment was completed in 2009, and Endeavour Ridge is being instrumented in September 2010, This system now provides the continuous power and bandwidth to collect integrated data on physical, chemical, geological, and biological gradients at temporal resolutions relevant to the dynamics of the earth-ocean system. The ridge is a very dynamic system, with many processes occurring episodically, so having a long continuous, high resolution and concurrent data set is essential to understand it. Beyond the continous data streams, NC provides the opportunity to react to events with control of instruments that cannot be operating continuously (e.g. water sampling, images acquisition). Some opportunities for integration and collaboration include:

Seismologic network and ridge tectonics
This will allow accurate location of seismic events at the ridge
Events will be automatically detected in real time
Detected events can trigger detailed observations:

- Temporary increase of sampling rate
- Pictures
- Water Samples
- Events sent out by email, text message, or automatic response of instruments

- Boreholes (maybe BPRs) acting as monuments can be used to monitor tectonic uplift and subsidence and response to local seismic events
- Elucidation of the structure of the ridge and mantle beneath. Longer time-series results in better images and show variations over time.

Hydrothermal vent monitoring
- COVIS (Cabled Observatory Vent Imaging Sonar) Monitoring individual vent 3D plume structure and flow characteristics
- Sampling physical and chemical water properties as a response to events.
- Continuous temperature and resistivity, to monitor heat and chemical exchanges between the earth's crust and ocean

Regional circulation monitoring
- Currents and water properties (temperature and salinity) in rift valley, to establish background circulation and water property structure for all experiments at the vent sites.
- Proxy measurement of the integrated hydrothermal fluid flux, through the seabreeze effect.

Vent ecology
- Digital camera
- Tempo-mini: camera with oxygen, temperature probes and chemical analyser.
- Microbial incubator for study of (geo)microbial processes
- Long-term surveys: follow changes in community structure and dynamics (species composition and abundances, interactions within and among species)
- Time-series studies provide a mean of studying population dynamics, biological rhythms, organism growth, faunal succession, biological interactions as well as the response of species and communities to environmental changes at different temporal scales (i.e. from minutes to years)
- In the case of the Marine Protected Area, Endeavour vent field, it is important to understand the dynamics of the ecosystem and the speed of its evolution for a better ecosystem and resource management.

Considering physical implications of petrological, geochemical, and seafloor morphology inferences on mantle heterogeneity and melting

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Ridge 2000 studies of seafloor lava samples have produced petrological and geochemical results that have implications for mantle melting, scales of heterogeneity, and a sense of crustal magma distributions. Considering these results in light of existing mantle flow and melting models (10-200 km depths) may allow determination of the range of mantle physical parameters that would allow the observed scales of variability/delivery patterns. In many cases, current models do not provide immediate tests, but discussions at this meeting should narrow the field of new numerical experiments that can produce predictions tied more directly to R2K data, such as the new results on H2O contents along the Lau spreading center. 2-D models of Lau mantle wedge flow that account for prescribed water content and distance between trench, arc and spreading center are available as a starting point for this ISS (Harmon and Blackman, accepted EPSL 2010). As results of the underway seismic imaging experiment along the ELSC become available, additional physical constraints can be combined with the current (and any future) geochemical constraints. Moving to a 3-D model will be key for more completely addressing system dynamics. Discussions at the workshop can guide the emphasis of the early 3-D numerical tests, where seismic anisotropy measurements will be linked to the flow modeling.

White papers on degassing and morphologic systematics in relation to mantle/melt properties also suggest an avenue to more closely tie seismic properties of the crust and uppermost mantle (2-15 km depths). Discussions during the workshop could focus on the quantitative measures already available in (active) seismic results from each ISS and whether there are additional steps with existing data that would bring this type of investigation to fruition. For example, what is the range of observed porosity variability along/across strike and in what depth intevals does it occur? How does this fit with degassing/compositional predictions? Is there evidence for lower crustal/uppermost mantle structure (e.g complex Moho transition zone) that could contribute to some of the anisotropic signal that has been interpreted soley in terms of mantle flow pattern?

Finally, since my most active field work during the Ridge 2000 program up to now (about to change as the Lau OBSs are recovered this Fall!) has been at the Mid-Atlantic Ridge, I hope to bring recent perspectives on slow-spreading systems into our discussions at relevant points. If there are synthesis topics where a broader suite of spreading centers can be included, it could increase the impact of any integrative publications that are an outgrowth of the workshop.

Oceanic fixed nitrogen sinks and associated bacterial communities in the hydrothermal vents of the Juan de Fuca Ridge

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Nitrogen is a building block of proteins and is thus an essential macronutrient for all organisms. Oceanic N sinks that remove bio-available N ultimately affect both photosynthetic and chemosynthetic primary productivity. A better understanding of bacterially-mediated N-cycle dynamics is thus essential to understanding metabolic processes taking place in the subsurface biosphere of hydrothermal vent systems. Furthermore, the relative importance of the two main N-elimination pathways (i.e. denitrification and anammox) in the global ocean is still a matter of debate and has never been explored in hydrothermal systems.

For my Ph. D research at the University of Victoria (British Columbia, Canada) I am studying the nitrogen (N) cycle and the related microbial community in subsurface hydrothermal systems of the Juan de Fuca Ridge (North-East Pacific Ocean) by applying a combination of biogeochemical and molecular biology methods to sampled vent fluids.

I began my project by analyzing the isotopic composition of dissolved inorganic N (nitrate and ammonium). These findings inform us about the biological transformations related to the N-cycle in hydrothermal vents. I have also measured rates of several N-removal processes (denitrification, anaerobic ammonium oxidation (anammox) and dissimilative nitrate reduction to ammonium (DNRA)) using labelled 15N incubation techniques. The second phase of my study involves using molecular biology techniques to identify the various organisms involved in the N-cycle. I am using 16S ribosomal RNA (16S rRNA) sequence information (anammox) as well as targeting specific functional genes (i.e. genes encoding the enzymes necessary for N-removal processes, i.e. denitrification and DNRA). This approach is allowing me to characterize the diversity and abundance (using q-PCR assays) of the microbial community and identifying the organisms responsible for major N-removal transformations in hydrothermal vent systems.

I expect to contribute substantially to my working group during the Ridge 2000 Program at the 2010 Community Meeting by bringing new essential information about N-cycling in hydrothermal vent systems and writing a part of a potential paper on the subject. To the best of my knowledge, I will be the only scientist working on bio-available N-removal in hydrothermal vents at the meeting. For several reasons (listed below), a section on bio-available N is indispensable in a synthesis paper about biogeochemical processes in hydrothermal vents. My combined biogeochemical and molecular biology approach will allow me to contribute a comprehensive synthesis of N sinks in hydrothermal vents to the group discussions and to the preparation of a synthesis manuscript. I also provide first measurements of the isotopic composition of dissolved inorganic nitrogen, rates of major N-elimination processes and characterization of the diversity and abundance of the related microbial community.

So far, geochemical and microbiological data documenting N-cycling in hydrothermal fluids have been extremely scarce because of sampling and analytical limitations. This Ph. D project is unique and only possible because of the numerous collaborations with scientists from around the world (i.e. University of Washington (USA), University of Basel (Switzerland), Max Planck Institute (Germany), University of British Columbia (Canada)) that allowed sampling pure hydrothermal vent fluids and several specific analyses to be done.

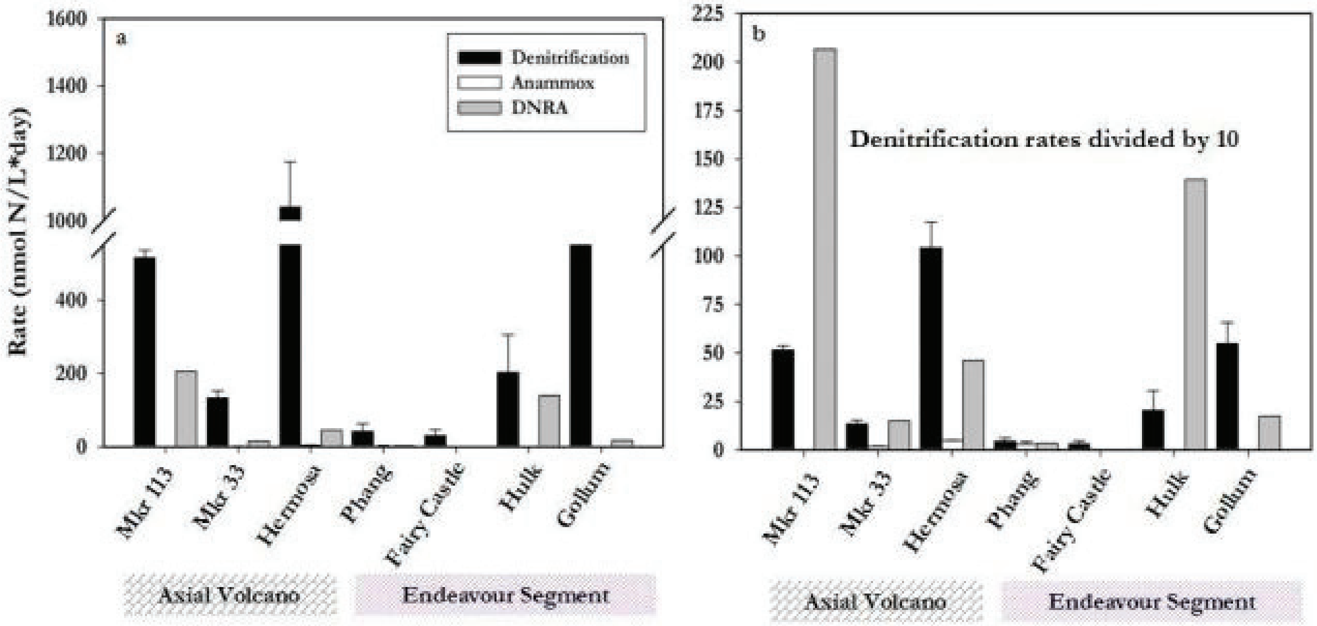

Figure 1. Denitrification, dissimilative nitrate reduction to ammonium (DNRA) and anammox at Axial Volcano and Endeavour Segment (Juan de Fuca Ridge, North-East Pacific ocean) (**a**). Water samples were collected during the cruise AT15-47 on board the RV Atlantis in June 2009. In (**b**), denitrification rates are divided by 10 to better show the relative importance of DNRA and anammox. These results suggest that denitrification is by far the dominant N-elimination process in the hydrothermal vents of the Juan de Fuca Ridge.

The influence of biogeochemical processes on the exchange of material between the lithosphere and the oceans

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Hydrothermal plume biogeochemical processes dictate the net effect of hydrothermal venting on the oceans just as estuarine biogeochemical processes dictate the net effect of river discharge. Previous hydrothermal studies have produced a largely abiotic conceptual model of hydrothermal plume formation (Mottl & McConachy, 1990; Rudnicki and Elderfield, 1993), and estimates of associated chemical fluxes (Kadko 1993; Elderfield and Schultz, 1996; German and Von Damm, 2000). However, there is also a body of evidence suggesting that hydrothermal plume chemistry is influenced by biotic processes as well. The first such indications were provided by Cowen et al. (1986), who reported microbially-catalyzed Fe/Mn oxidation-precipitation reactions plumes of the Juan de Fuca Ridge. Several other studies have since shown evidence of enhanced microbial CH4 and Mn oxidation in neutrally buoyant hydrothermal plumes (e.g. De Angelis et al., 1993; Mandernack and Tebo, 1993; O'Brien et al., 1998).

Within the last decade, a number of studies have provided new evidence for a coupling between abiotic and biotic plume processes. There has been new evidence of biomass production and microbial activity within plumes (Dick et al. 2009; Wakeham et al. 2001). Dynamics of specific microbial groups such as Mn- and ammonia-oxidizing microorganisms have been identified (Dick et al. 2009; Lam et al., 2004; Lam et al., 2008). There has been evidence that Mn-oxidizers can produce highly reactive biogenic Mn oxides (Dick et al. 2009). And recent studies also indicate that organic carbon binds a significant fraction of the dissolved and particulate metals in hydrothermal plumes by the processes of complexation (Sander et al. 2007; Bennett et al. 2008), and aggregation (Toner et al., 2009; Breier et al. submitted). In fact these studies suggest multiple mechanisms through which abiotic plume chemistry is coupled with biotic plume processes. These couplings are important from three perspectives: (1) hydrothermal energy sources stimulate microbial activity and productivity and potentially structure plume microbial communities; (2) microorganisms mediate the fate of elements and energy transferred from deep-sea hydrothermal vents into the water column; and (3) the aggregation of organic and inorganic material has a strong influence on the transport and fate of hydrothermal material and seawater scavenged trace elements.

This topic is timely, because recent studies suggest that processes active in hydrothermal plumes may significantly affect global ocean budgets. Specifically, it is now estimated that hydrothermal plumes may supply up to 25% of all deep-ocean dissolved Fe, which may also buffer the ocean Fe cycle on time-scales of 1000s yrs from short term (on the order of yrs) perturbations by processes such as aerosol deposition (Bennett et al. 2008; Tagliabue et al. 2010).

Issues of chemical transport and microbial utilization bear directly on those estimates. These issues, and the evidence and hypotheses associated with them, are ripe for synthesis and a synthesis paper could be developed to describe a coupled abiotic-biotic model of plume transport (see figure). Moreover, many of the underlying mechanistic abiotic-biotic couplings are not unique to the plume; but must also manifest themselves at and below the seafloor, and a complete understanding of chemical exchange between the lithosphere and the oceans must synthesize data and models across all of these zones. The biogeochemistry thematic working group will be a good forum for discussing these topics.

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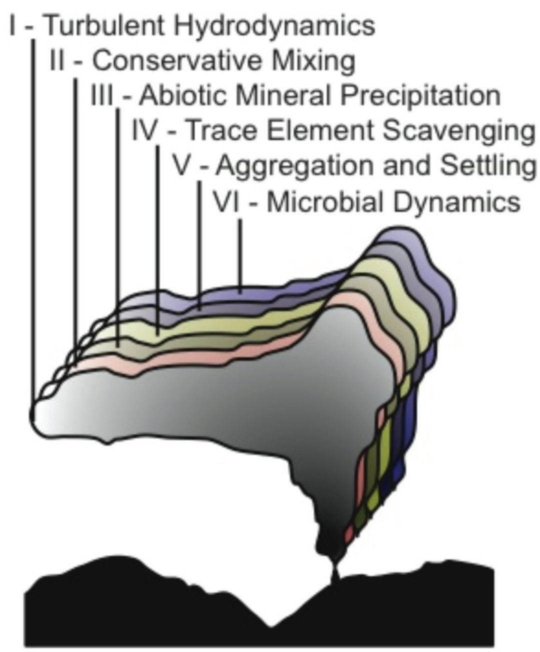

Merging reaction path models with spatial and temporal data on ridge systems to predict the timing and location of microbial habitat generation

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Reaction path modeling has long been a useful tool in evaluating complex processes in natural systems by quantifying reaction progress. One of the strengths of reaction path modeling is that it is independent of time and space. However, this can be a barrier to relating the results of reaction-path calculations to the spatial and temporal constraints that define natural systems. The complexities of mapping calculations onto nature are amplified when unraveling biogeochemical processes that involve all of the abiotic and biotic constituents of the system. Nevertheless, overcoming these obstacles will permit new insights not attainable by reaction path modeling alone. Merging model results with observational and geochemical/physical data from Ridge 2000 will also lead to predictions of the timing and location of microbial habitat generation not otherwise possible.

Previous investigations using reaction path modeling reveal only slight differences among MORB alteration assemblages and the resulting fluid compositions regardless of moderate differences in equilibration temperature, or fairly wide ranges of water-to-rock ratios. As examples, calculated pHs, silica activities and hydrogen concentrations are quite similar even when using MORB compositions that span the range of observations. In contrast, ultramafic assemblages yield far more variability, consistent with experiments and observations of natural systems. In order to understand these systems though, water-rock-microbe interactions and their consequences must be investigated with respect to space and time across the moving reference frame of the ridge system. To portray these processes in a more tangible way, model results using data from a variety of ridge systems can be presented in the form of affinity diagrams using combinations of reaction progress, time, and composition to deconvolute the biogeochemical processes of the system. In this way, the conditions of real systems can be mapped spatially and temporally to link the nonequilibrium thermodynamics of water-rock alteration with the nonequilibrium processes of metabolism and biosynthesis. This approach permits insights into the habitability of diverse geochemical systems as they evolve along/within a ridge segment through both space and time. The outcome will be new interpretations of the succession of microbial populations as spreading occurs and when linked to temporal data on volcanic events, earthquakes and the subsequent changes in the geochemistry of mineral assemblages and fluids, can aid in predicting habitat generation, sustentation, evolution, mortality and migration.

Comparisons of the EPR and Endeavour ISS: Near-axis melt anomalies, segmentation of axial melt, and propagating ridge offsets

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Comparisons of crustal properties at the EPR and Endeavour ISS reveal commonalities that bear on a number of long-standing questions including the origin and significance of ridge axis segmentation, influence of mantle melt anomalies on ridge processes, and driving forces for ridge propagation.

1. Influence of mantle melt anomalies on ridge axis structure
Both the EPR and Endeavour sites are adjacent to off-axis seamount chains and proximity of these local melt anomalies is presumably linked to localization of magmatism at both sites. The Lamont seamounts are located immediately west of the EPR "bulls eye" (9°49-9°51'N). Here, the ridge axis and the underlying mid-crust magma lens reach the local shallowest point along the ridge, hydrothermal venting is clustered, and the lavas with highest Mg# have erupted [Perfit et al., 1994]. Similar relationships are observed at Endeavour segment where the hydrothermally and magmatically active portion of this segment coincides with the on-axis projection of the Heckle seamount chain. An axial magma lens is present only beneath the central shallow portion of the segment where active venting is also focused. Seismic data indicate thicker crust has been accreted within this central portion of the segment for the past 0.7 Ma coincident with timing of ridge intersection with the Heckle chain. An important prediction of the ridge-melt anomaly interaction apparent at these sites is that regions of locally enhanced axial magmatism are likely to persist for long time periods (10's– 100's of ka) and longevity in the axial hydrothermal system is also expected.

2. Fine-scale segmentation of crustal melt
On a local scale, fourth-order segmentation of the mid-crustal magma lens plays a key role in the variability in seafloor volcanism and hydrothermal activity at both sites. At the EPR, segmentation of the axial magma lens into discrete overlapping lenses with along-strike dimensions of 5-10 km is evident in a new 3D multichannel seismic reflection data set. The main clusters of hydrothermal venting at the EPR site (at 9°49'-50' and ~9°46-47') are underlain by discrete lenses. Fine-scale geochemical sampling within the region reveals variations in major element geochemistry, also linked to the underlying magma lens segmentation. Although the detailed geometry of the magma lens at Endeavour segment can not be confidently established without a 3D seismic survey, the existing 2D seismic reflection data indicate magma lens segmentation on a similar scale may be present, with a discrete lens beneath the Mothra vent, offset from a shallower lens beneath the vents to the north. Along-strike differences in geochemistry of axial lavas may be linked to this segmentation.

3. Structure of propagating offsets and driving forces for ridge propagation
Early observations of seafloor structure at modern propagating ridges indicated that the magmatic ridge tip is typically located 10-20 km behind the extensional rift tip. Recent observations of discordant zones left by propagating ridge offsets at both the Endeavour and EPR sites reveal a local zone of thicker crust is present at roughly the same location, and local melt anomalies associated with propagating ridge tips are inferred. On the JdF plate, a 10-20 km wide zone of thicker and possibly denser crust is found on the young crust side of pseudofaults left by former propagating offsets [Marjanovic et al., in prep.]. A sequence of bright ridge-ward dipping sub-Moho seismic reflections underlie the region of thicker crust and are interpreted as frozen melt sills at the base of the crust emplaced behind the propagating ridge tips [Nedimovic et al., 2005]. These frozen magma lenses are presumably the source magma bodies for the denser, iron-enriched crustal rocks found above and within the adjoining pseudofault zones. Similarly, at the southward propagating 9°03'N OSC at the EPR site an ~20 km wide band of crust that is both thicker and denser is located behind the v-shaped discordant zone left by the OSC propagation [Canales et al., 2002; Toomey and Hooft, 2008]. At the southern edge of this band of thick crust, Singh et al. [2008] find evidence for a large melt anomaly in the lower crust and anomalously thick crust at the propagating eastern ridge of the OSC. The presence of local melt anomalies beneath

propagating ridge tips presumably contributes to the forces driving ridge propagation in these regions. These melt anomalies may arise from small shallow mantle compositional or thermal anomalies. Alternatively, as the propagating ridge advances into colder preexisting lithosphere, damming and accumulation of melts due to the strongly 3D topography at the base of the lithosphere may be important.

Multi-channel seismic imaging study of the magmatic system at the EPR 9°50’N ISS

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Among all the properties of a magma lens one might want to investigate, its presence, its width and its vertical position in two-way time to the seafloor are the most readily obtained from multi-channel seismic reflection imaging (of which the first product is an “image” in either two-way time of wave propagation or depth if a reliable large-scale velocity field is available). Thickness of the magma lens (in the absence of a distinct bottom reflection which has not been convincingly imaged so far), the detailed velocity structure (P and S-wave velocities within the lens as well as immediately above and below), and precise estimation of the melt content represent more difficult information to extract, with detailed analyses typically carried out at discrete locations. Such quantitative information however brings powerful constraints that shed light on the interactions between the magmatic system and the hydrothermal system (e.g., high-velocity hydrothermal roof capping the melt lens inferred near 14°S on the Southern EPR), and can be incorporated in modeling studies. If the seismic acquisition is conducted as a 3D survey, proper focusing of out-of-plane energy (otherwise commonly the source of ambiguities in 2D sections) results in enhanced resolution of the resulting images, and the data density and continuity in two directions of space is such that both small-scale features can be detected and larger structures can be mapped and studied in fine detail. That turn can help select the best target locations to apply advanced seismic methods for detailed quantification of magma lens properties, such as 1D or 2D elastic full waveform inversion.

3D seismic data processing of the 2008 Langseth EPR data at the 9°50’N ISS is being carried out to generate a post-stack time migrated volume providing a view of the 3D distribution of magma lens reflectors (both on and off-axis), within an ~20km across-axis by ~27km along-axis area processed with a grid cell size of 6.25m across-axis by 18.75m along-axis. The axial melt lens is ~500-600m wide beneath the northern vent cluster, and ~1km wide beneath the southern vent cluster, with great geometrical complexity especially visible within, but not limited to, the fourth order ridge axis discontinuities. An event at the same two-way time to the seafloor and labeled “frozen top” of the axial magma chamber on the 1985 Conrad lines is not present in coincident Langseth data, which suggests it might have been an artefact related to the reverberatory nature of the seismic sound source. Also consistently imaged in the Langseth data volume are the layer 2A event (turning ray which once projected to zero-offset is generally interpreted to mark the extrusives/dykes contact), and the Moho (though not directly beneath the axial magma body). Some coherent sub-horizontal events are imaged within the extrusives at the ridge crest, while the subsurface continuation of faults observed at the seafloor is not imaged perhaps due to the lack of a strong enough acoustic impedance contrast. Off-axis melt lenses are detected as reflectors identical in character to the axial melt lens: frequency content, polarity, shape on stacked images with broad edge diffractions which if imaged alone could be misinterpreted as dipping reflectors within the crust. The OAMLs are imaged in a variety of positions, both vertically (from a shorter two-way time below seafloor than the axial melt lens, to sub-Moho) and in distance to the axis (nearest at ~1km, furthest at ~17km), and seem to be roughly equi-dimensional bodies. Like for the axial magma body, work beyond the production of a well-focused image is required to determine the thickness and melt content of the off-axis magma bodies.

Microbial adaptation to intense physicochemical gradients

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A conspicuous inhabitant of certain high temperature (40-105°C) deep-sea (> 2500 m) hydrothermal vent habitats is the polychaetous annelid *Alvinella pompejana* A. pompejana is found on the walls of high temperature vent chimneys from 13° N to 32° S along the Eastern Pacific Rise (EPR) and has been described by a number of research groups as one of the most thermotolerant and eurythermal metazoans on this planet. Adult worms are found on black smoker chimneys, where they construct tubes directly on the chimney wall. Temperature probe measurements taken inside actively venting worm-inhabited tubes document the potential for worms to be frequently exposed to steep thermal gradients, with a temperature differential up to 60°C or more along the worm's body. The environment of diffuse flow habitats surrounding the worms' tubes has been characterized not only by its temperature, but also by high levels of hydrogen sulfide (>1 mM) and high concentrations of heavy metals (0.3-200μM). These diffuse flow sites consist of areas of intense mixing of end-member type fluids with ambient seawater creating thermochemical gradients that are unmatched anywhere else on the planet.

The degree to which A. pompejana is 'adapted to' or merely 'tolerant of' short-term high temperature exposures is unknown. While A. pompejana appears to flourish in this extreme environment, worms inhabiting low temperature chimneys are more exposed to predation, suggesting that the high temperature chimneys may be a thermal refuge for A. pompejana, with associated costs for living under elevated temperatures. Indeed, analysis of mRNA transcript abundance for several heat shock proteins (HSPs) in a large EST library suggests a higher level of stress for worms inhabiting sites with elevated temperatures compared to those at lower temperatures. HSPs are expressed under stress and aid in folding proteins, consuming ATP in the process. They are regulated at the level of gene transcription, so that transcript abundance may be used as an indicator of heat stress. Analysis of HSP transcript abundance in A. pompejana demonstrates up to 3-fold higher expression of HSPs in posterior vs. anterior sections of worms as well as in worms inhabiting high temperature tubes vs. low temperature tubes. This suggests the cost of living at elevated temperatures may be much higher than living in cooler temperatures for A. pompejana, and that this species may seek out high temperature environments not out of preference, but as a refuge from predation.

We have been conducting an interdisciplinary study to investigate the metabolic ecology and adaptation strategies associated with living in a thermal gradient. For this project, we seek to answer the following questions:
1. What is the range of temperatures for habitat selection for A. pompejana?,
2. What are the metabolic consequences of living in a thermal gradient for A. pompejana?
3. What temperature-adaptive strategies (at both the cellular and genetic level) are employed by A. pompejana? New tools have been developed to more accurately measure the sustained physicochemical gradients in the tubes of individual A. pompejana and to successfully preserve the mRNA of individual specimens on the seafloor. These will be coupled with down stream comparative transcriptome analysis to resolve the genetics of thermal adaptation. Results of this investigation will provide insight into metabolic and physiological constraints that influence habitat selection in ecosystems characterized by thermal gradients. In addition, the identification and elucidation of temperature-adaptive strategies will advance our understanding of the evolution, physiology and ecology of organisms living in extreme environments.

How are volcanic eruptions distributed in time and space along mid-ocean ridges, and how do they relate to hydrothermal, seismic, and biological activity?

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Observations of fresh lava flows coupled with the injection of biogenic particles into the water column and seismicity demonstrated that eruptions can trigger seismic, hydrothermal, and biologic activity. Understanding the factors that control eruptions is critical to understanding the linkages between volcanic eruptions, faulting (earthquakes), hydrothermal venting, and biological activity. Yet, few data are available that document the volume, timing, and spatial extent of volcanic eruptions, and this paucity of direct evidence makes it difficult to investigate linkages with other ridge processes.

To maximize the probability of catching an eruption in the act, the Ridge2000 strategy has been to focus investigations at “bull’s eyes”, sections of the ridge axis that display large cross-sectional areas. Indeed, inflated segments are generally thought to be subject to more frequent and/or more voluminous eruptions. The common occurrence along such segments of fresh-looking lava flows, of shallow melt lenses (as revealed from seismic surveys) and of hydrothermal plumes support this model. However, the paucity of investigations at counterpart magmatically starved segments (i.e., segments with small cross-sectional areas) makes for an uncomplete test. Some linkages may be overlooked because factors other than magmatic “robustness” probably also control the timing and styles of volcanic eruptions. For example, static stress changes induced by the intrusion of a dike or by an earthquake may sometime be sufficient to trigger diking at a neighboring segment. A diking event without associated seafloor eruption would also affect hydrothermal circulation, and therefore biological activity.

I am interested in discussing existing evidence for linkages between eruptions and seismic, hydrothermal, and biological activities. Two recent and on-going experiments will contribute material for such discussion. A linear array of 19 bottom pressure recorders (BPRs) have been deployed since March 2007 between 9°N and 10°N along the EPR that will be recovered early in 2011 (coPIs Cormier, Buck, and Webb). BPRs can detect vertical motion of the seafloor with a resolution of just a few cm and should capture any diking event that occurred during that 4 year-period over a 100 km section of the ridge axis. The other dataset include repeat water column profiling (“tow-yo” surveys) along that same length of the EPR. It documents large variations in the intensity of hydrothermal plumes that seem correlated with time since last eruption.

Co-registration of historical maps of Icelandic rift zones reveal changes in shallow crustal permeability and hydrothermal systematics in concert with local seismic and magmatic events: Implications for investigation of the R2K focus.

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Preliminary co-registration of several generations of available geological data was carried out for the Hengill and Krafla hydrothermal fields along active rift zones of the Iceland plate boundary zone. Initial results indicate significant short-term and long-term changes in hydrothermal outflow locations, flow rates and styles, and hydrothermal fluid characteristics over short periods in concert with recorded earthquakes, dike intrusions, and fissure eruptions. Higher resolution, more detailed maps covering the time-periods in question are being collected for integration and analysis.

Initial results from the Hengill and Krafla geothermal areas covering a time-span of nearly 40 years at ~10 year intervals indicate the following:

1. the surface expression of fault populations change in character very little, with the exception of local fault and fracture systems;
2. there is evidence for significant changes in vent population locations over that same time period, with either older vents shifting location, or new vents opening and old vents closing;
3. there are areas of high vent population density mapped over a 10-year span that are absent from both previous and later maps, and areas of little or no hydrothermal activity over that same 10-year span that host significant hydrothermal vent populations in both earlier and later maps;
4. changes in vent (and/or vent field) temperature and flow rate, as well as vent eruptive style are similarly observed in successive map generations;
5. significant local seismic and volcanological events (earthquakes, earthquake swarms, dike intrusions, eruptions, inflation/deflation) take place in intervening years between production of successive maps that are potential triggers for the observed changes.

Higher resolution maps of these hydrothermal systems, specifically maps that have been converted to GIS data objects containing detailed vent location and temperature, chemistry, and flow-rate data are being collated and collected for a more in-depth and detailed analysis.

There is significant potential for this type of analysis to be used to understand the interplay between tectonic activity, fault populations and hydrothermal outflow characteristics over very short time-scales. Along more intensively surveyed segments of the MOR, there may be potential for detailing similar temporal and spatial correlative relationships between short-term geological/geophysical events and the shallow architecture of the mid-ocean ridge crest.

Entrainment as a function of horizontal cross flows and their affect on hydrothermal plume vertical velocity and turbulence

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Deep sea hydrothermal plumes are driven by gravitational buoyancy forces and may coalesce with plumes from nearby sources and rise up to hundreds of meters above the orifice. Ambient ocean water is entrained into the plume during its ascent which makes the plume diluted and cooled. Long term measurements of physical properties of hydrothermal plumes are limited and such properties are of crucial importance for understanding 1) how the plume interacts with the ambient oceanography, 2) how turbulence levels affect mixing within the plume and 3) how entrainment as a function of horizontal cross flows is an important component for modeling plume dynamics.

In Sept 2007 an acoustic scintillation system was deployed in the Main Endeavour vent Field to specifically quantify the long term temporal variability of the vertical velocity and turbulence of the hydrothermal plume of Dante at 20 m above the top of the sulfide structure. The distance between the vertical array of transmitters and receivers was 91m and line-of-sight alignment was 19 oT along the Endeavour axis which was aligned with the direction of the dominant horizontal flows. Six weeks of data was collected. Using the space-time coherence of the acoustic amplitude signal, hourly vertical velocity measurements were obtained. Theoretical developments comparing acoustic forward scattering from turbulence and from particles show that suspended particles having a measured density of 3.88 x 104 particles/m3 produce negligible amplitude fluctuations compared to turbulence modeled by an isotropic and homogeneous Kolmogorov model for the temperature variability.

The vertical velocity and turbulence of the hydrothermal plume measured 20 m above Dante shows a significant correlation with the horizontal flow which is comprised of tidal and subtidal oscillations aligned with the axial valley. The residual flow to the northeast is significant (~ 4 cm/s) and can increase the horizontal flow during the flooding tide and diminish the horizontal flow during the ebbing tide. The hydrothermal plume of Dante and its interaction with the horizontal flow within the Main Endeavour Field can be generalized as follows: 1) the plume’s vertical velocity is maximum when the horizontal flow is weakest (during the ebbing tide) while it is a minimum when the horizontal flow is strongest (during the flooding tide); 2) the turbulent intensity within the plume reaches a maximum when the horizontal flow is weakest (during the ebbing tide) while it reaches minimum when the horizontal flow is strongest (during the flooding tide). When the horizontal flow is weak (during the ebbing tide), less ambient ocean water is entrained into the plume. In such a case, the plume is faster and hotter and the turbulent velocity and temperature fluctuations increase within the plume. When the horizontal flow is strong (during the flooding tide), more ambient ocean water is entrained into the plume. In such a case, the plume is slower and cooler with reduced turbulent velocity and temperature fluctuations.

Results from an integral plume model based on the conservation equations of mass, momentum, density deficit and dissolved tracers and taking into account ambient stratification and horizontal cross flows are compared with the acoustic scintillation results and several conclusions are reached and generalized as follows: 1) radius of the plume produced by Dante increases linearly along plume’s height above the orifice; 2) vertical velocity of the plume decreases exponentially along the plume’s height
and is enhanced during ebbing tide while suppressed during flooding tide; 3) The plume’s terminal height (where vertical velocity goes to zero) increases during ebbing tide and decreases during flooding tide; 4) the bending of the plume is enhanced during flooding tide and diminished during ebbing tide.

A poster outlining these ideas will also be presented.

Microbial biogeochemistry in deep-sea hydrothermal plumes: revealing the processes, players, and implications of microbially-mediated geochemistry.

Greg Dick
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Deep-sea hydrothermal plumes host dynamic interactions between microbial communities and geochemical processes: hydrothermal inputs fuel enhanced microbial activity, while microorganisms catalyze geochemical transformations and thus mediate the transfer of material between vents and oceans. In addition, plumes are conduits for transport of microorganisms and larvae and thus represent biogeographic connections both between environments within vents fields and between different vent sites. Recent results highlight the intimate nature of interactions between biology and geochemistry in plumes (Bennett et al. 2008, Dick et al. 2009, Dick and Tebo 2010, Toner et al. 2009, Tagliabue et al. 2010) while highlighting gaps in understanding of the microorganisms that determine rates and end-products of biogeochemical processes.

Key questions that remain largely unanswered include: (1) what is the nature of microorganisms that are active in deep-sea hydrothermal plumes (e.g. derived from seafloor vs. background deep sea), and how does this vary within plumes (e.g. rising versus neutrally-buoyant) and across geochemical gradients? (2) To what extent do microbes influence biogeochemical processes in terms of rates, speciation, and end-products (e.g. biogenic minerals)? (3) Which hydrothermal inputs serve as the major energy sources for chemolithoautotrophy in plumes, and what are the implications for feedbacks onto biogeochemical functions? Such information is a prerequisite if we are to reach a deeper understanding of the impact that deep-sea vents have on the chemistry and biology of the oceans.

Our ability to address such questions has been limited by technical challenges but new tools provide great promise for breaching these barriers. In particular, advances in sampling (Breier et al. 2009) and investigating chemical speciation (Toner et al. 2009) and microbial communities (Dick et al. 2010) provide new windows into plume processes and the spatial, temporal, and biological dimensions in which they occur. My laboratory has been applying metagenomic and metatranscriptomic approaches to characterize the metabolic potential and function of plume microbes; such approach hold enormous potential for addressing the questions above.

Given the importance of plume microbial biogeochemistry, its interdisciplinary nature, the fact that it has been understudied for some time, and the promise of recent results and approaches, this topic deserves a prominent role in R2K discussions and synthesis efforts.

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Refining timescales and magnitudes of recent volcanological and geochemical variability at Axial Seamount, Juan de Fuca Ridge

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Geochemical, structural, and morphological variability at intermediate-spreading ridges are manifestations of mantle-melting and magmatic differentiation processes and their complex interplay with tectonism. Because melt production, transport, accumulation, and eruption processes can vary on the segment-scale over decades (Rubin et al., 2005), MOR study requires the ability to identify, sample, and date individual flow units (Rubin et al., 2001) in order to capture a representative range of volcanological and geochemical variability through time. Even when detailed seafloor observations or mapping exists (e.g., the Juan de Fuca Ridge) understanding the fine-scale petrologic, volcanologic, and magmatic evolution of mid-ocean ridges requires evaluating age relationships among lava flow sequences (Christie, 1994, Rubin & MacDougall, 1990). Here we detail recent results at Axial Seamount, which is part of a larger collaborative study to investigate timescales and magnitudes of geological, volcanological, and chemical variability on the southern JdFR (including CoAxial and northern Cleft).

Axial Seamount hosts the shallowest (~1.5 km bsf; Carbotte et al., 2008) and likely most robust axial magma chamber of the JdFR. Migration of the JdFR due to northwesterly absolute plate motion has led to intersection with the Cobb hotspot and magma oversupply at the present site of Axial Seamount since <0.5 Ma (Karsten & Delaney, 1989). Multibeam mapping and coregistered sidescan data collected with MBARI's AUV D. Allan B. at Axial Seamount since 2006 total ~73 km2 and include the horseshoe-shaped summit caldera (3x 8x 0.15 km) and rim. The only known eruption of Axial Seamount occurred in 1998. Lateral dike injection and eruption were associated with an earthquake swarm (Dziak & Fox, 1999) and produced vigorous sheet lava flows and abundant pyroclasts (high effusion rate) from at least two collinear fissures at the southern end of the caldera (Chadwick et al., 2006, Embley et al., 1999, Fox et al., 2001). West et al. (2001) suggest that melts reside in the crust beneath Axial Seamount for hundreds to a few thousand years, but inflation since the 1998 eruption suggest that the magma chamber will be replenished in just ~22 years (Chadwick et al., 2006, Nooner & Chadwick, 2009).

Petrochemical and morphological variability, recorded in historical and older lava sequences, offer insight into timescales and pathways of melt generation and differentiation and replenishment in crustal reservoirs. A chronological framework for lava sequences is constructed using uranium-series model ages of the lavas and radiocarbon ages of coexisting benthic and planktic foraminifera at the sediment-lava contact. (We have requested NSF funding to supplement these efforts with geomagnetic paleointensity methods.) Our observation of >10 distinct, large aphyric, very lightly sedimented (and therefore <500a) lava flows within the caldera suggests an eruption recurrence of <50 a. Further, our seafloor observations and preliminary data suggest a significant petrogenetic change occurred beneath Axial Seamount within the last millennium. Eight dated lava flows from the summit caldera and flanks have eruption ages of 600-1200a, MgO ≥7.5 wt%, and are plagioclase-phyric. In contrast, younger lavas (undated but with thin sediment cover) from the same areas are aphyric with lower MgO, possibly reflecting enhanced crystal separation or longer magma residence times since ~600 a.

A higher degree of magma mixing (homogenization) in the magma reservoir beneath Axial Seamount is inferred from a limited range in trace element ratios (e.g. La/Yb; Chadwick et al. 2005 and our unpublished data) compared to lavas from adjacent segments, but modern radiogenic isotope data are too sparse to evaluate. Our data confirm that Axial Seamount has the lowest (230Th)/(232Th) on the JdFR axis but (230Th)-excesses are similar to adjacent segments. These observations suggest that source compositions are more variable than melting processes on the southern JdFR. Like Axial Seamount under the influence of the Cobb hotspot, inflated crust at Endeavour segment is associated with the source of the nearby Heckle Seamount. However, there are fundamental unresolved differences between these two sections highlighted by (230Th)-excesses and geochemical variances at Endeavour that are much higher than elsewhere else on the JdFR.

Contrasting crustal production and rapid mantle transitions beneath the Eastern Lau Spreading Center

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The opening of back arc basins behind subduction zones progresses from initial rifting near the volcanic arc to seafloor spreading [Karig, 1970]. During this process, the spreading ridge and the volcanic arc separate and lavas erupted at the ridge evolve from heavily subduction influenced (with high volatile contents derived from the subducting plate) to much less so [e.g., Hawkins, 1995; Pearce et al., 1995; Martinez and Taylor, 2002; Escrig et al., 2009]. The present axis of the Eastern Lau Spreading Center (ELSC) is a key region over which the mantle source composition changes from arc-like (Valu Fa ridge to the south) to MORB-like (Central Lau Spreading Center to the north). This and other systematic variations in axial crustal properties have been attributed to the changing proximity of the ridge to the arc volcanic front [Pearce et al., 1995; Martinez and Taylor, 2002]. The observations are consistent with a general decreasing "subduction-influence" in the mantle as the ridge shifts away from the arc. Virtually unstudied until recently however, is the across-axis evolution of subduction influence, which reveals the continuous history of changing mantle influence as each section of ridge has moved further from the arc.

Recent seismic tomography and geophysical studies of the ELSC show that changes in upper crustal seismic velocity closely mirror changes in seafloor morphology and depth and gravity. Together with sparse off axis geochemical data, these observations delineate distinct crustal domains with step-like transitions between them. We infer that the abrupt changes in crustal properties reflect rapid evolution of the mantle entrained by the ridge, such that stable, broad triangular upwelling regions, as inferred for open-ocean mid-ocean ridges [Forsyth et al., 1998; Conder et al., 2002], cannot form near the mantle wedge corner. Instead, the observations imply a dynamic process in which low-viscosity subduction-influenced mantle buoyantly entrained in the ridge upwelling zone near the arc is suddenly 'released' as the ridge system moves away from the arc and switches to passive upwelling, with consequent rapid changes in crustal properties. This hypothesis also explains rapid geochemical changes measured along the ridge axis [Escrig et al., 2009]. As individual spreading segments move further from the volcanic arc, they 'let go' of the low-viscosity arc-influenced mantle at different points in time.

Missing from this story are densely spaced off-axis geochemical samples that are needed to document the melt supply during the history of spreading. Existing axial samples and the very few off-axis samples cannot be used to test the hypothesis of rapid changes in the mantle source composition with spreading. We suggest a dedicated campaign to collect off-axis samples to further document changes in the chemical nature of the melt supply.

Crystallization and Axial Depth Along the East Pacific Rise

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Segment-scale axial depth variations along fast-spreading mid-ocean ridges like the East Pacific Rise (EPR) have traditionally been associated with magma supply and/or mantle temperature, yet geophysical observations along the northern EPR preclude these hypotheses. Recent studies show instead that increasing axial depth along the EPR between the Clipperton and Siqueiros transforms correlates with an increase in both crustal density and offset of mantle upwelling with respect to the ridge axis. The observed increase in axial depth can be explained by an ~0.1 g/cc increase in bulk crustal density.

We use thermodynamic modeling (MELTS) to show how density variations on the order inferred along the northern EPR can result from differences in crystallization depth. Regions where lower crustal formation occurs by deep crystallization have higher average crustal density than those where the lower crust is generated by subsiding cumulates originating within an upper-crustal, axial magma chamber (AMC). Our modeling results demonstrate that the density variations are attributed to differences in the crystallization sequence of major minerals at different pressures.

Because higher crustal density also correlates with regions of off-axis mantle upwelling, we suggest that lateral transport of melt to the rise axis, by up to 20 km or more, generates flow conditions favorable for deep crystallization. Moho-depth crystallization is inferred to occur during and/or post-migration, likely thickening the Moho transition zone. We also suggest that regions of rise-centered upwelling generate flow conditions favorable for shallow crystallization, where mantle melt ascends more efficiently to the AMC before any significant fractionation can occur. Our modeling results quantitatively link segment-scale variations in axial depth and crustal density to segment-scale variations in crystallization depth. In this view, axial highs are associated with magmatic systems that crystallize melt preferentially within upper-crustal magma bodies. Conversely, along-axis deeps are associated with magmatic systems that have significant near-Moho crystallization, a condition that we attribute to off-axis delivery of mantle melt.

Explosion and Volcanic Debris Records from West Mata Volcano, Northeast Lau Basin

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During two cruises in November 2008 and May 2009, a spectacular explosive eruption was discovered at the summit of West Mata Volcano in the northeast Lau Basin (Resing et al. 2009). This submarine volcano is located ~150 km southwest of Samoa, between 15°00'S and 15°10'S. In December of 2009, we re-initiated acoustic monitoring of the West Mata system by deploying four hydrophone moorings during a research cruise of opportunity. This array, recovered in late April 2010, was configured in a diamond-shaped geometry encompassing the summit and a set of nearby volcanic edifices known as the North Matas (Fig. 1). Each mooring contained a single sound-channel moored hydrophone (~300-1000 m depth) with a sample-rate of 1 kHz. The southern mooring in the array also contained two optical backscatter and temperature sensors (MAPRs) attached to the mooring line (at 1800 and 2250 m depth) to detect plumes of volcanic debris that detach from the flank of West Mata.

The presence of prolonged and intense eruptive activity makes the northeastern Lau Basin an ideal system to gain insight on deep-ocean volcanism and its impacts on the ocean. We would like to combine our hydrophone and in situ MAPR data with other ship-based water column and geophysical measurements to investigate several first-order processes.

We hypothesize that: 1) Volcano-acoustic signals from the Northern Lau Basin are produced by multiple, some yet undiscovered, sources along the summit of West Mata. This creates a natural laboratory through which we can study the impact of water depth on submarine eruptions. 2) Variable frequency harmonic tremor observed at submarine volcanoes like West Mata can be modeled as a series of discrete explosion events. Such a discovery would alter the existing paradigm for submarine tremor generation, which relates this process to resonance within the magma conduit. 3) The relative production of volcanic ash and debris plumes, as monitored by the in situ MAPRs deployed near West Mata, can be correlated with the intensity and style of acoustic signals sourced from the volcanic edifice. This work seeks to unravel the time history of volcano growth and the transport of clastic material from the summit.

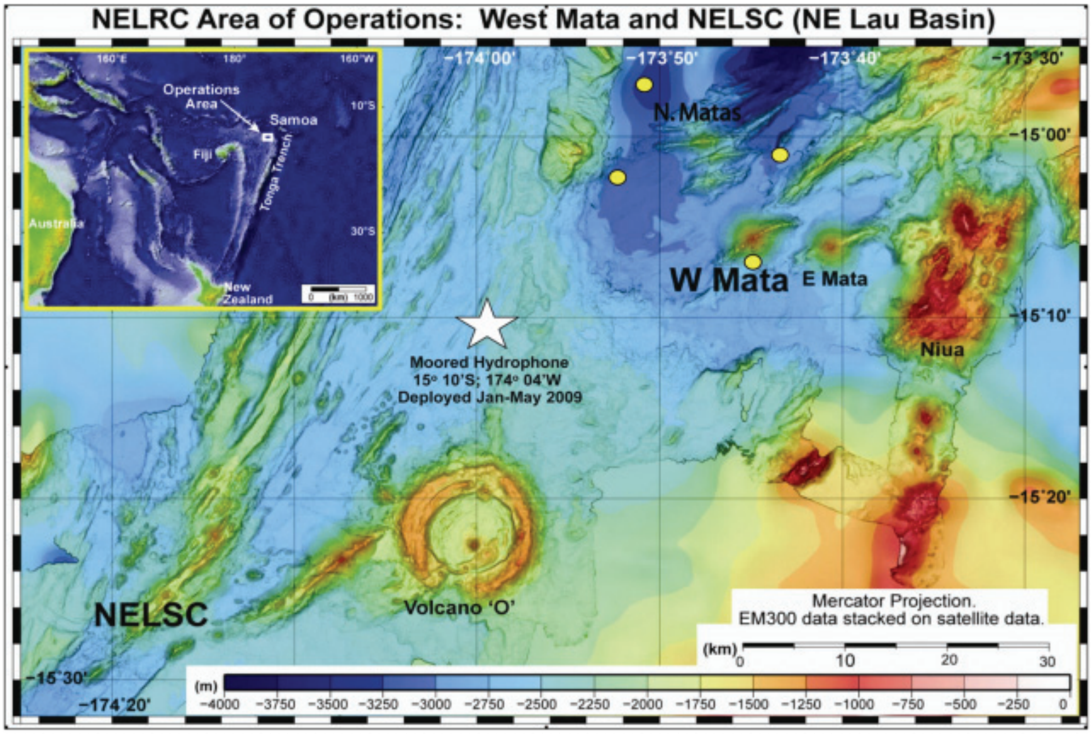

Figure 1: Map showing location of West Mata volcano and other significant volcanoes in the northeast Lau Basin. White Star denotes location of moored hydrophone deployed from January to May 2009. Location of West Mata hydrophone array deployed from December 2009 to April 2010 also shown (yellow circles). NELSC is abbreviation for Northeast Lau Spreading Center. Inset map shows location of study area relative to Fiji and Samoa. Map courtesy of S. Merle.

Modeling hydrothermal circulation at the East Pacific Rise ISS site

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One of the most important issues concerning hydrothermal circulation at ocean ridge axes is the location, size and orientation of the recharge zone. Mathematical models argue that anhydrite precipitated from heated sea water would rapidly reduce porosity and permeability of the high temperature recharge zone and thus affect the thermal characteristics of high temperature venting, unless recharge occurs over a wide area. On the other hand seismicity data from the fast-spreading East Pacific Rise (EPR) have been used to argue that hydrothermal recharge occurs over a relatively small region that is strongly aligned along the ridge axis and that strains generated by seismicity could maintain porosity and permeability even in the event of anhydrite precipitation.

We are attempting to reconcile these two points of view by applying more advanced mathematical and numerical models to the EPR hydrothermal cell at 9°50' N to determine whether the seismicity distribution observed at EPR near 9°50' N delineates the recharge zone for the overlying hydrothermal system. Using a combination of thermal, geochemical, and seismic data on the depth to the subaxial magma lens as constraints, we developed a preliminary model of hydrothermal circulation along approximately 2 (km) of ridge axis from TWP to the Bio9 vent complex. Using Mg and Si data collected at EPR as conservative tracers and the observed partitioning of heat transport between high temperatures focused flow and low temperature diffuse flow provides additional constraints on the hydrothermal system behavior. These analyses show that at least 80% of the total heat flow comes from magma sources. We find that the sub-axial magma chamber must be actively replenished on a decadal time scale, which is consistent with recent petrological data. Although a simple 1-D model indicates that the seismically inferred recharge zone may not be large enough to carry all the flow without clogging as a result of anhydrite precipitation, preliminary results from the 2-D numerical model suggest that anhydrite precipitation might occur over broader regions and not have as strong a sealing effect.

Future numerical studies will incorporate temperature and time-dependent permeability by assuming a relationship between porosity and permeability and will include a model for the solubility of anhydrite as a function of temperature in order to investigate the feedback of anhydrite precipitation on the circulation. We also hope to devise a method to estimate the effects of seismicity on temporal changes in porosity and thus determine whether seismicity data can be used to estimate rates and scales of crack generation and opening of new flow paths as anhydrite seals old ones.

Advances in Data Sharing Related to the Ridge 2000 Program

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A principle goal of the Ridge 2000 Program is to develop focused, quantitative, whole-system models of Oceanic Spreading Center processes through coordinated, integrated, and interdisciplinary experiments at a small number of sites. Pivotal to achieving this goal is an emphasis on interdisciplinary collaboration through the timely dissemination of data and results. The Ridge 2000 Data Management Office (DMO) was established to assist the science community in meeting their data sharing requirements by (1) establishing the infrastructure to document field programs and provide access to field and derived data sets, and (2) developing tools and services to facilitate the discovery, analysis, and integration of data funded by and related to the Ridge 2000 Program.

Accomplishments

Ridge 2000 Data Portal (www.marine-geo.org/portals/ridge2000) was established as part of the integrated Marine Geoscience Data System (MGDS, www.marine-geo.org). At its core, the Ridge 2000 Data Portal includes an inventory of field programs and sampling activities, and provides access to raw and derived data sets held within the data system and hosted at specialized disciplinary data systems (e.g. PetDB, www.petdb.org; GenBank, www.ncbi.nlm.nih.gov; IRIS, www.iris.edu, NGDC, www.ngdc.noaa.gov). The data system was designed to fully document field program activities such that scientists not in the field can discover relevant information about data acquisition activities. The system links information about sampling and surveying activities to the resulting data, provides basic provenance information linking field (raw) data with derived (processed) data products, and links data to references and NSF award information. Data are discoverable through several web applications including text-based and map-based search interfaces, OGC-compliant web services, and Google Earth services. As the system has evolved and more data have become available, functionality has been added to accommodate new data types, leverage emerging technology, and adapt to the needs of the user community.

In addition to the main database, the Ridge 2000 DMO has constructed two desktop applications for data visualization and analysis. GeoMapApp (www.geomapapp.org) and Virtual Ocean (www.virtualocean.org) provide geographic context (map-view) for a variety of online data sets hosted by the Data Portal and by partner data systems (e.g. geochemical data hosted by PetDB, near-bottom imagery hosted by NDSF). These tools not only access online data but also provide options to import data from the user's local computer. They are important tools for facilitating integration and synthesis across disciplinary boundaries by making specialized data sets (e.g. geophysical data) visually and quantitatively accessible to users from other disciplines. In addition, these tools make available the Global Multi-Resolution Topography (GMRT) synthesis (www.marine-geo.org/portals/gmrt) which serves as the bathymetric basemap for several papers and presentations.

Evolving developments in partner data systems have also played an important role in Ridge 2000 data management efforts. The System for Earth Sample Registration (SESAR, www.geosamples.org), part of the Geoinformatics for Geochemistry (GfG, www.geoinfogeochem.org) Program is a centralized registry that provides and administers unique identifiers for geoscience samples. The use of International Geo Sample Numbers (IGSNs) prevents ambiguity in documenting samples by systematizing sample designation and ensuring that all information associated with a sample is preserved for accessibility on a global scale. A partnership between SESAR and the Ridge 2000 Data Portal ensures that IGSNs for samples registered with SESAR are made available through the Data Portal search interface and GeoMapApp.

As the Ridge 2000 Program has progressed, the emphasis on data sharing and preservation across all NSF-funded programs has increased, and the culture within the science community with respect to data sharing has begun to shift. More and more scientists are routinely submitting data, and sharing data is becoming an integral aspect of how we conduct our research, collaborate, and build upon each other's work. As a result of increased community engagement and technological advances, data submission, access, and analysis tools are constantly evolving. The design of the integrated data system has enabled rapid development of new functionality and interfaces in response to the needs of the Ridge 2000 Program. Recent system enhancements include the development and release of an integrated data compliance web form to help PIs document the status of their data submissions, and a fully integrated reference search that provides access to field program information and data sets based on publications.

Much of the functionality developed within the Ridge 2000 Data Portal has been scaled up and applied to data management efforts for other NSF-funded programs (e.g. MARGINS) and the broader community of ocean scientists. Database design and functionality developed by the Ridge 2000 DMO has been used to build a prototype database for the National Deep Submergence Facility (NDSF), and to create a next generation digital event logger for use with NDSF vehicles to facilitate accurate documentation of sampling metadata. In addition, Ridge 2000 data management efforts have informed developing and evolving data management efforts at NSF and NASA. Lessons learned and technical achievements should also help inform parallel data management strategies such as OOI.

Future Directions

An integrated data system that serves the needs of the science community is much more than a catalog of metadata and archived data with a single data access interface. A well-designed data system that provides a variety of data access options ensures that the system can leverage emerging technology and provide customized access for a diverse community of users. Fundamental to the success of such a system is that it be populated with high-quality metadata that describes the digital data collection. While documenting data can be very time consuming for certain data types, some tools for routinely capturing metadata have already been developed. In the future, we can expect that more tools will be constructed and refined to facilitate our efforts to routinely document data. Further, as data format standards are accepted for more data types, tools that can leverage those standards will facilitate data submission. Integrated online tools for online data submission are already being designed as part of the formal partnership between MGDS and GfG (Integrated Earth Data Applications (IEDA)). Consolidating existing data submission information and tools for these systems into a centralized location, will help clarify data submission requirements and provide information to the community about new data submission tools as they come online.

As technology evolves data sharing will become the norm as the culture of the science community changes to accept this new paradigm. As data are more frequently used by scientists not involved with initial acquisition of the data, data publication and citation will become integral to publishing in peer-reviewed journals. As data sharing becomes more broadly recognized as a critical component of the modern scientific process, we are likely to see professional credit given for data submission.

Significant new scientific discoveries will inevitably result from increased data sharing. In addition to an increase in the rate of growth of regional and global data compilations, more data will be available to construct and validate models that investigate earth processes. Data management activities will continually evolve, leveraging new computer technology and increasing bandwidth to improve data discoverability, facilitate collaboration, and meet the evolving needs of a growing scientific user community.

Microbial-basalt interaction

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The paper by Mason et al. "First investigation of the microbiology of the deepest layer of ocean crust" (submitted) shows that microorganisms found 400 to 1400 meters below the sea floor in ocean gabbros are capable of oxidizing organic compounds. Some of the organics appear to be catalyzed at temperatures above 100°C in the crust or upper mantle in the presence of igneous minerals. This organic matter is transported in fluids to the crust where it can react with oxidants from seawater. If this oxidation occurs at temperatures below 120°C, then it can support a microbial biosphere in the crust. The paper by Heberling et al. ("The extent of the microbial biosphere in the oceanic crust" Geochemistry, Geophysics, Geosystems, 2010) indicates that this oxidation is can occur in the upper 1 to 5 kilometers of the ocean crust. The paper by Smith et al., "New method for selective enrichment of microbes in sub-seafloor minerals and glass" (in preparation) demonstrates an in situ method of obtaining microorganisms from within a borehole in the ocean crust. In that study igneous minerals were incubated in a borehole in ocean crust Layer 2A for four years and then recovered. Some to these organisms that were enriched on the minerals appear to be capable of oxidizing organic compounds and iron with nitrate. These studies indicate that within the ocean crust, organic compounds and iron from igneous minerals can be oxidized even under anaerobic conditions. This environment is certainly reproduced on Mars where water, iron-rich igneous minerals, methane, and low levels of oxidants coexist in the subsurface. These studies point to specific future goals of (1) investigating microorganisms from the ocean crust, (2) identifying organic compounds in hydrothermal fluids, (3) further development and use of in situ subsurface microbial samplers, (4) modeling of subsurface microbial environments, and (5) applying this new understanding to the search for subsurface life on Mars.

Abiotic Controls of Microbial Biogeography in Deep-Sea Hydrothermal Vent Deposits

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Deep-sea hydrothermal environments support highly productive biological communities. These communities thrive in the complete absence of sunlight because Archaea and Bacteria are able to harness the abundant geochemical energy available in the hydrothermal fluids. Numerous studies have attempted to describe the free-living bacteria associated with active hydrothermal vent deposits from around the globe. While these studies have provided an inventory of the types of organisms present in these environments, relatively few studies have attempted to understand the abiotic controls on microbial biogeography at the vent field scale. Through our recent work at the Mid-Atlantic Ridge (MAR), we have been able to show that environmental factors, particularly hydrothermal fluid chemistry and fluid mixing styles, can have a dramatic impact on microbial community structure and composition. Community differences are evident at phylogenetic and functional levels within and between individual vent fields along the MAR. We are currently extending this research to other vent fields, including the East Pacific Rise (EPR) and Eastern Lau Spreading Center (ELSC), in order to elucidate other abiotic factors that may influence microbial community composition and structure. Integrating our microbiological data with the existing geochemical and microbiogical data from the EPR and ELSC will be vital for us to determine other abiotic controls of microbial biogeography.

Time Series Temperature Measurements at MOR Hydrothermal Vents

Dan Fornari[1], Florencia Meana-Prado, Julie Bryce[2], Tim Shank[1], Marvin Lilley[3], Karen Von Damm* (*deceased 15 August 2008)

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2. University of New Hampshire

3. Oregon State Univ

Fluid temperatures at high-T and low-T hydrothermal vents at the EPR have been monitored nearly continuously since 1993, following the volcanic eruptions in 1991-1992 using several types of self-recording loggers (e.g, HOBOs for high-temperature vents and Vemcos for low-temperature diffuse flow areas. Data from the EPR high-T loggers (HOBO™) and Alvin temperature probe measurements provide the most complete temporal histories of vent fluid temperatures for any global MOR hydrothermal site. HOBO™ data recorded prior to and during the 2005-06 EPR eruptions are being correlated and reconciled with geophysical, fluid chemistry and biological data that span the eruption period from prior to mid-2005 to early 2006 (Von Damm et al. in preparation). These data will be available at the 2010 meeting and have been submitted to the Ridge 2000 database at MGDS and may be accessed there by contacting the PIs and MGDS. Upon submission of the paper in the coming few months, access to these data will be unrestricted.

It would be useful to compile and correlate other fluid temperature time series data collected at other ocean spreading center hydrothermal vents, both within ISSs and elsewhere, to investigate both general trends in vent temperature history with biological community evolution, and vent fluid chemistry where available. Additional correlations to microseismicity data for discrete periods would also be important to include. This type of synthesis can shed light on first-order correlations between controlling phenomena at MOR axial vents.

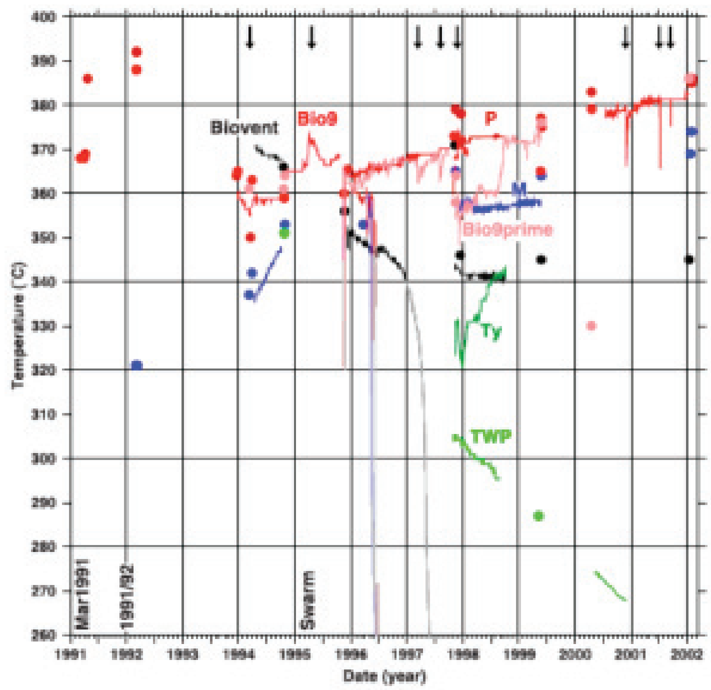

Figure 9. Fluid temperature variation between 1991 and 2002 at four focused flow, high-temperature vents in the EPR Biotransect area (Bio9, Bio9prime, P, Ty, TWP) and at two focused flow vents (Biovent, M) located ~1 km north of the northern limit of the Biotransect. Discrete measurements made while sampling fluids from these vents are shown as dots [*Von Damm*, 1995, 2000]; continuous measurements with HOBO probes are shown as colored lines. Gray lines indicate when the continuous records reflect temperatures associated with vent sealing, chimney toppling, or other causes not related to changes in the vent effluent. Arrows indicate times of temperature excursions of one or more of the vents.

Figure 1. Reprinted from Figure 9 in Scheirer et al., [2006; Q03002, doi:10.1029/2005GC001094], showing both punctuated measurements of high-T vent fluid temperatures since the 1991 EPR eruption [from Von Damm, 1995 & 2000] and continuous (every 15-30 minutes) fluid temperature measurements made using HOBO loggers through 2002.

Figure 2. (A) Photographs taken from Alvin during At15-6 (RESET06) cruise in June 2006 when the HOBO logger was recovered from M vent. The presence of the logger was identified in TowCam photographs taken on the R/V New Horizon (NH06) 'event-response' cruise in May 2006 (logger housing is visible at bottom-middle of photo in B). Visual observations of the logger prior to recovery and photo-documentation carried out when the logger was deployed in 2004 using Alvin shows that the new lava covered the bottom ~1 m of the M-vent chimney, while the crust of the new flow was <0.25 m from the logger housing (top left photo above). M-vent was no longer active in late June 2006 and has remained inactive up through late 2007.

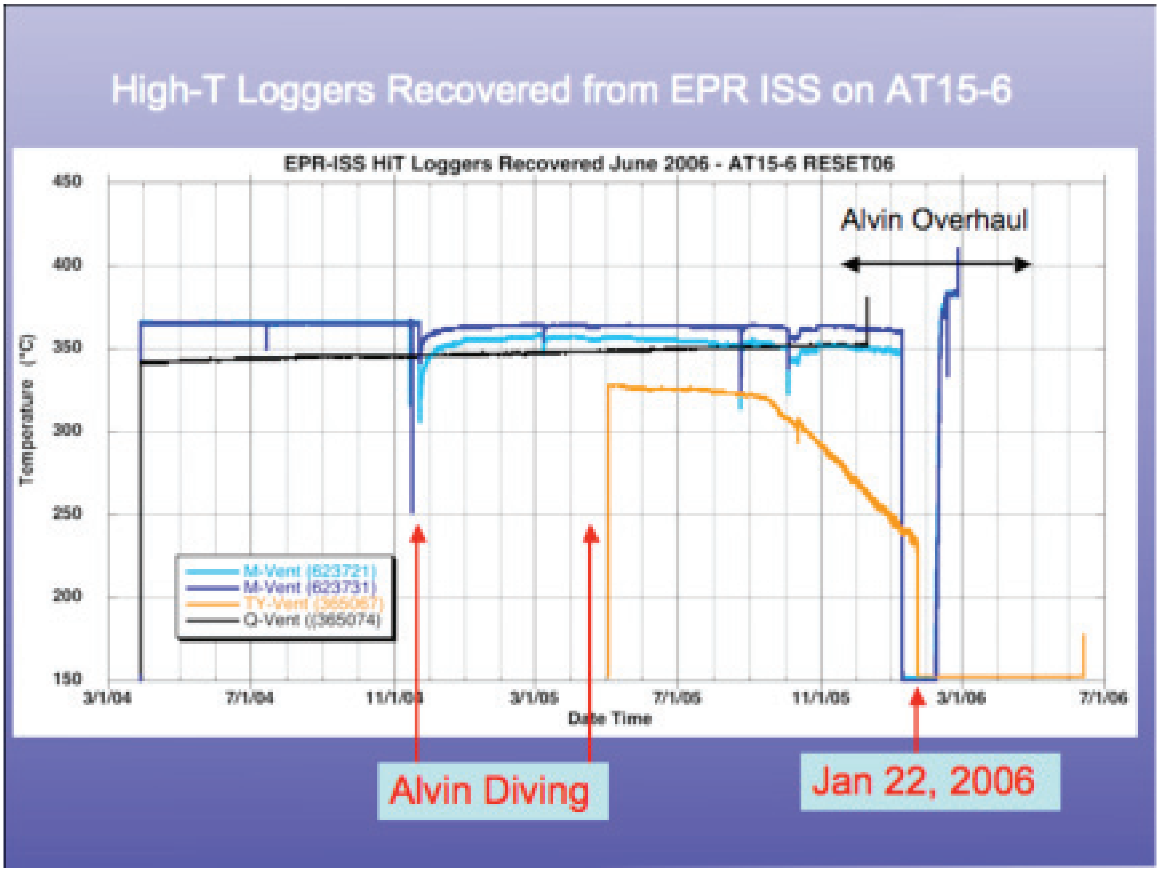

Figure 3. Data from 3 HOBO high-T loggers recovered by Alvin on the AT15-6 cruise (June 2006) post-eruption (K. Von Damm, unpublished data). M-vent data are the most compelling in terms of their potential to help correlate microseismicity data, Po age-dating of lava [Rubin et al., 2006, 2008] and fluid chemistry variations pre- and post-eruption in order to help constrain eruption timing, episodicity and processes associated with the most recent, documented EPR eruption. Blue lines show recordings from two separate platinum RTD (resistance temperature device) sensors and logging chips in the HOBO housing deployed at M-vent. Very stable temperatures in the vent are apparent from April 2004 to August 2005 (note times when record was perturbed by Alvin manipulation at the vent are shown by red arrows). Post August 2005, the fluid temperature at M-vent fluctuated with several sharp reductions followed by rapid recovery to the ~360°C level, which preceded the suspected onset of the 2005-06 eruptions [e.g. Rubin et al. 2006, 2008]. On January 11, both logging chips recorded a dramatic fall in temperature that occurs nearly instantaneously, falling below the 152°C minimum recording temperature of the RTDs used in these loggers. Clearly, the high-T fluid flow at M-vent was disrupted on Jan 11, 2006, but surprisingly after about 2 weeks, the temperature climbed suddenly to levels above 360°C and increased over a ~2 week period by nearly 20°C to ~380°C after which the battery power in the logger fell below operating current and the recordings stopped. The Jan. 22 seismic crisis reported by Tolstoy et al., [2006] is shown and post-dates the steep drop in M-vent temperature by ~11 days. Drift in the HOBO logger's clocks are of the order of a few minutes per month so the magnitude of the temporal difference between these events is not due to the instrumentation. Correlation and modeling of the M-vent temperature record with the microseismicity data and fluid chemistry will help establish linkages between processes controlling high-T venting at the EPR and clarify possible timing of eruptive phases in the 2005-2006 time period. Data for Q vent and Ty vent are also shown.

Experimental Constraints on the Metabolic Rates and Growth Efficiency of Seafloor Microbial Communities across Redox and Thermal Gradients

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Understanding the basic microbiology and biogeochemistry of deep-sea hydrothermal ecosystems is essential to constrain the extent of deep-sea and subsurface biosphere and to evaluate the role of microbial metabolism on the fluxes of inorganic/organic nutrients and the bio-signatures imprinted in the chemical composition of low-temperature hydrothermal emissions. A number of field and laboratory culturing studies have been conducted to better describe these biogeochemical processes; however, there is presently a complete lack of experimental studies to evaluate the effect of redox gradients on the metabolic rates and growth efficiencies of anaerobic and microaerobic organisms at seafloor pressure conditions..

While thermodynamic models have emerged as very important tools to inform about potentially important biogeochemical processes occurring at vents, and to make estimates on overall biomass production, a number of assumptions go into these models, and there is a strong need for actual data derived from cultivated microbes. For example, existing thermodynamic models predict an abrupt transition between oxic (oxidation) and anoxic (reduction) conditions that reflects the relative distribution of redox species in the hydrothermal fluid/seawater mixture and the ΔGr energy for each individual redox reaction. Experimental data demonstrating inhibition of the Knallgas reaction at low temperatures (<100oC), however, suggest that active bacterial population in near-seafloor habitats could potentially utilize both H2(aq) and O2(aq), while anaerobic chemolithoautotrophic metabolism can be feasible at temperatures lower than 40oC due to H2(aq) persistence in the seawater/vent fluid mixtures. In effect, under H2-O2 disequilibria conditions the anoxic/oxic boundaries along mixing interface may not be as sharp and microbial-mediated H2(aq) oxidation could provide one of the largest energy sources available at the low-T diffuse flow vent sites.

Thus, novel experimental approaches need to be developed to facilitate controlled laboratory studies on microbial metabolism and biogeochemical processes under extreme conditions. For example, experimental designs can include continuous culture flow-through approaches that would allow for the assessment of specific relations between different metabolic pathways and microbial adaptability across a spectrum of anaerobic/aerobic conditions and by utilizing a range of substrate compositions (e.g. H2, CO2, SO4--,NO3-) while exposing microbial communities to physical conditions that resemble deep-sea environments. Such experimental studies are essential for defining and for thoroughly describing the mass transport and mechanisms of biomass production associated with microbial metabolism at sites of deep-sea hydrothermal activity, which is fundamental for:

- Identifying the effect of redox gradients (relative availability of e--donors/acceptors) present in seawater/hydrothermal fluid mixing zones on microbial growth and the metabolic pathways of (anaerobic) chemolithotrophs
- Estimating bioavailable energy along anoxic/oxic boundaries in seafloor mixing zones, and identifying major metabolic pathways at the extreme conditions of active submarine hydrothermal systems
- Constraining the extent and spatial variability of subsurface biosphere to define the C, N, S, and Fe biochemical cycling in mid-ocean ridges, based on experimental data on the rate of microbial metabolism and the flux of metabolic products in near-seafloor hydrothermal environments

Examining the Distribution of Functional Capacity and Metabolic Activity of Endolithic Microbial Communities within Hydrothermal Vent Structures

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The high diversity of vent-hosted microbes, their substantial biomass, and the timescale on which water circulates through hydrothermal vents suggest that these microbial communities likely contribute significantly to global biogeochemical cycling. However, the ecology of hydrothermal vent microbial communities and the broader impact of these organisms on marine biogeochemical cycles is poorly constrained. Based on chemical and thermodynamic models, specific metabolic pathways have been predicted to dominate these systems but few have been experimentally confirmed (McCollum and Shock, 1997). To date, we have a limited understanding of which biogeochemical reactions occur within chimney structures, the kinetics of these processes, the influence of these processes on the microbial community structure, and the extent to which they influence various marine or global elemental cycles.

In order to investigate these questions, the functional capacity and metabolic activity of these communities must be characterized. The study of environmental constraints on microbial colonization within active sulfide structures has been limited by the lack of assessments of in situ conditions in conjunction with microbial distribution within single structures. Advances in sampling and sequencing technologies are continuously allowing better characterization of the biogeochemical impact of these microorganisms within hydrothermal vent environments. An in situ incubation instrument (recently developed with Deb Kelley) allows for the characterization of microbial communities in the context of long-term co-registered measurements of temperature and fluid chemistry. Our ongoing integration of metagenomic data with metabolic rate measurements aims to examine the key environmental and energetic parameters for microbial community assembly in hydrothermal sulfide environments.

While our knowledge of vent environments has grown considerably, many questions remain regarding the abundance, distribution, and metabolic characteristics of these endolithic communities. With the development of new molecular tools and innovative sampling devices, a more in depth analysis of these communities will begin to answer questions about the role of these systems in global biogeochemical cycles. The complexity of these environments requires a multidisciplinary approach to correlate fluid chemistry, mineralogy and geology with microbiology at all levels of resolution. Only then will we begin to constrain the biogeochemical impact of hydrothermally hosted vent microorganisms.

Lava Morphology and Geochemistry: Insights into MOR eruption dynamics

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In order to understand the physical expressions of MOR events at various scales and thus the linkages between seafloor geology and crustal magmatism, it is important to be able to identify and study individual eruptions. By investigating lava morphologic characteristics associated with seafloor volcanic eruptions in conjunction with the geochemistry of the individual flows, we can begin to better understand how and why (i.e., erupted volumes, effusion rates, eruption processes and dynamics) they vary between MOR sites and ridge segments.

The 2005-2006 eruption at the EPR ISS marked the first observed repeat eruption at a mid-ocean ridge and provided a unique opportunity to deduce the emplacement dynamics of submarine lava flows. Seafloor photography and high-resolution bathymetric profiles from deep-towed camera surveys have been used to produce a geologic map of the volcanic features associated with this eruption near 950N. Our analysis of the distribution of lava flow morphologies emplaced during 2005-2006 shows that seafloor lava morphology is primarily controlled by eruption rates at the vent and their variability along axis and with time. We also show that the dynamics of the 2005-2006 eruptions were substantially different than previous eruptions along this segment of the EPR.

In addition to our investigation of the geology of the 2005-2006 flows, we have also conducted geochemical analyses of basalts sampled by a ROV along the walls and floor of a flow channel created during the eruption. Our analyses show that despite the distance the flow covered (~3 km), little crystallization or chemical fractionation occurred – hence little cooling, which agrees with the rapid extrusion rates inferred from the surface morphology. This suggests that for rapidly emplaced axial-derived flows, post-eruptive crystal fractionation at fast-spreading MORs is not a prevalent petrogenetic process and is not responsible for geochemical heterogeneity on the crestal plateau. Other possibilities for creating across-axis geochemical heterogeneity include temporal variation in magma petrogenesis or off-axis eruptions sourced from distinct magma bodies.

Our study can be integrated and compared with data collected at other ISS and MOR sites in general, particularly where individual eruptions have been identified (i.e., Southern East Pacific Rise, Juan de Fuca Ridge, and Lau Spreading Center), to examine the primary controls on volcanic deposition at different sites and within the same sites over time.

Sulfur speciation in the diffuse flow zones of Lau Basin

Amy Gartman
University of Delaware

Using in-situ electrochemical sensors, we mapped the temperature, oxygen, H2S, partially oxidized sulfur species, as well as FeS and Fe2+ in the diffuse flow environments of Lau Basin, in coordination with macrofaunal mapping done by Chuck Fisher's group. We can now compare changes in all of these chemical species from 2006 to 2009, using the more than 10,000 scans from each cruise. Trends in diffuse flow chemistry can also be viewed in comparison to the high temperature focused flow chimneys from the same vent sites. For example, sulfide to temperature ratios for the diffuse flow zones exhibit little change from 2006 to 2009, while for focused flow, the sulfide significantly decreased. Average temperature for some diffuse flow zones has increased while the S to T ratio remains constant, indicating greater overall sulfide from some sites, in contrast with lower temperature and lower sulfide from focused flow sites. Additionally, the partially oxidized sulfur species thiosulfate and polysulfides have been measured. These partially oxidized sulfur species are not temporally stable and so can only be detected using in- situ techniques. The concentrations of these oxidized S species directly correlate with the concentration of H2S at a given site.

Comparison to EPR integrated study site

The partially oxidized sulfur species, thiosulfate and polysulfides, have both been detected in significant quantities at Lau Basin. In similar diffuse flow studies conducted at EPR 9oN, these species were identified, but in insignificant quantities. Possible explanations for the difference between Lau Basin and EPR are the presence of distinct fauna, and/or the presence of a more oxidized substrate at Lau Basin. Evidence for either of these possibilities in determining the difference in speciation between the sites will be explored, as well as differences found from North to South at Lau Basin.

Crustal controls on magma reservoirs at Endeavour

Jim Gill
University of California Santa Cruz

The Endeavour ISS is blessed with a larger than usual diversity of mantle-derived geochemical differences that allow its >250 submersible-collected basalts to be grouped into chemo-stratigraphic units that did not pave the entire width of the axial valley. These units represent separate differentiation-related 'magma batches', each reflecting separate mantle melting and crustal storage episodes that can be used to address crustal controls on magma reservoirs and the nature of mantle sources and melting. They show the following ten features. First, the greatest diversity of basalt types and, therefore, the least mixing between magma matches, occurs along the western margin of the axial valley where the melt lens terminates and where the largest hydrothermal vents are concentrated. Hence, both melts and fluids rise along faults there. Second, there is a first-order along-strike change in basalt composition where the melt lens is offset vertically south of Mothra. Third, the isotopic composition of Pb in hydrothermal systems has along-strike variations that may reflect those in the basalts which would indicate that the hydrothermal cells are at most a few km long. Fourth, all basalt types are most mafic (>7.5% Mg) at the northern end of the longest melt lens where the axial valley is shallowest. This seems to be the primary site of melt focusing. Fifth, basalts from at least several separate magma batches erupted in the axial graben within the last 104 years. Sixth, young basalts are common up to 2 km off-axis where they differ in composition and eruption style from the axial valley, and differ on one flank versus the other. Compositions on the east flank, which is partly underlain by the current melt lens, are the most uniform at Endeavour (7.0±0.1% MgO) and grade to somewhat more differentiated (lower temperature) compositions on both sides of the flank. Compositions on the far west flank are the least affected by the enriched mantle now tapped in the axial valley. The asymmetry between the flanks precludes their surface basalts from having formed in the axial valley and then separated by spreading. Seventh, many of the chemo-stratigraphic units show evidence of open system behavior (e.g., mixing between magma batches); e.g., variations in the ratios of incompatible trace elements and isotopes that exceed those caused by fractional crystallization or analytical error. Eighth, those units closest to closed systems have major element variations and maximum CO2 contents consistent with differentiation at depths near the current melt lens (2-3 km). Ninth, all basalts erupted in the axial valley or its flanks have the same distinctive enrichment in Th, Nb, and Pb isotopes as in the West Valley segment ~ 40 km north, whereas those erupted >3 km beyond the flanks do not. Heckle Seamounts also lack this enrichment. Therefore, although the Endeavour segment migrated over an enriched mantle domain within the last few hundred Ka, this does not directly explain its thicker crust and inflated topography. Finally, because the 230Th and 231Pa excesses are higher at Endeavour than elsewhere along the Juan de Fuca Ridge including Axial Seamount, the rate of mantle upwelling driving Endeavour magmatism is slower, not faster than elsewhere despite the greater melt productivity.

Allying microbial phylogenetic and functional diversity to the geochemical milieu: studying endolithic microbial communities via in situ laboratories

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Abstract

Hydrothermal vents are extremely dynamic, and the mixing of vent endmember effluent and seawater can be quite turbulent. Interestingly, we have observed that -within the porous sulfide walls of a chimney -stable temperature and fluid chemistry gradients may be established. Previous efforts (Schrenk et al, 2003) have shown that microbes living within these sulfides exhibit a zonation that may relate to these gradients, though the temporal and spatial nature of the observed zonation is poorly constrained. Furthermore, the successional nature of endolithic microbial communities - and the degree to which this is influenced by the dynamics of physico-chemical conditions - is largely unknown.

To investigate the microbial ecology of these structures at the Endeavour segment of the Juan de Fuca Ridge system, Deb Kelley and we developed and deployed a series of in situ endolithic incubators, consisting of titanium sleeves packed with sterile substrates equipped with temperature probes and small-volume water samplers. Samplers were deployed within the sulfides for periods ranging from one week to over a year. Patterns in phylogenetic and functional diversity suggest that specific archaeal and bacterial groups are early colonizers of hydrothermal sulfides. Via quantitative-PCR and FISH, we also observed temporal and spatial changes in the abundance of dominant endolithic phylotypes, which provide insight into the phylogenetic and functional "succession" within hydrothermal sulfides. Our ongoing geochemical and metagenomic analyses aims to examine which geochemical features -if any- are related to the observed microbial community dynamics and physiologies.

Contributions to Integration and Synthesis

While significant advances in vent microbiology have been made in recent years, there is a paucity of information on the endolithic microbial communities. These communities may have a pronounced influence on vent geochemical composition, and they likely play a significant role in carbon and nitrogen cycling within the vent community. We suggest that these relationships cannot be discerned or constrained without a concerted, multidisciplinary effort to relate the patterns in geochemistry, mineralogy and microbiology. To that end, we have used this project as a model for coordinating efforts and analyses, as well as integrating data with varying degrees of temporal and spatial resolution. We hope to discuss our results to date, as well as the logistical and organizational approaches that were most (and least) effective in this program. It is our overarching goal to work with the larger community in developing more sophisticated approaches to integrating and synthesizing disparate biological and geochemical datasets.

New paradigms for expanding education and outreach for oceanographic and earth science

Liz Goehring[1], Véronique Robigou[2], Kathy Ellins[3], Ellen Kappel[4], Tracy Barbaro[5], Christy Herren[6]

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2. *Oceanus et Terra Studio*
3. *University of Texas at Austin*
4. *Geo Prose*
5. *Encyclopedia of Life, Harvard University*
6. *University of Maine (COSEE-Ocean Systems)*

For nearly two decades, since the original RIDGE program began, ridge scientists have been finding ways to share the exciting discoveries of hydrothermal vent systems beyond the scientific community to public audiences of all ages, backgrounds and interests. With advances in communications and Internet technologies, new opportunities exist for telling the ridge story. Our working group brings a diverse set of backgrounds together to review outreach lessons learned and explore new approaches, technologies, and networks to expand our reach. This white paper describes some of the R2K outreach successes, potential future directions, and what each working group member brings to this endeavor.

Highlights of Ridge community E&O accomplishments

A more complete description of ridge-related outreach efforts and their impacts will be compiled during the meeting as part of the paper that will come from this working group.

<u>Experiential Learning for K-12 Teachers</u> – Teachers at Sea: Early efforts of RIDGE PIs resulted in the successful teacher-at-sea REVEL Project (Research and Education: Volcanoes, Life and Exploration). REVEL laid the foundation for a number of successful teachers at sea education projects including URI Graduate School of Oceanography's Teacher Armada and the IODP Deep Earth Academy Teacher at Sea Program.

"Seagoing expedition" web sites: R2K scientists at various institutions institutionalized "research expeditions web sites" to engage students (K-Graduate level), teachers, and the general public in the excitement and complexity of seagoing work. These web sites provide mid-ocean ridge scientific background, data, and spectacular imagery of life on board research vessels, the seafloor and its unusual inhabitants. To name a few: REVEL (UW), Black Smokers (AMNH), Dive & Discover (WHOI), Extreme 2000 - Voyage to the Deep (U Delaware). With the evolution of satellite-sea-land telecommunication, seagoing expeditions worldwide are accessible to the public (Canada, France (IFREMER), Japan).

<u>K-12 Curricular Resources:</u> To complement REVEL and expedition web sites and reach teachers and students throughout the U.S., the R2K E&O office developed the SEAS (Student Experiments at Sea) program, providing ridge-related curriculum resources for K-12 educators and a program for students to engage in authentic inquiry through the web. In 2006, R2K E&O collaborated with GLOBE, an international web-based science education program, to create FLEXE (From Local to Extreme Environments) and begin reaching schools worldwide. FLEXE is a Ridge 2000/GLOBE Earth Systems Science project that features inquiry-based, data-oriented activities designed for middle/high school level students to learn about the deep-sea in the context of their own environment.

<u>Informal Science Centers:</u> R2K researchers also have a successful history of working with informal science centers to develop deep-sea exhibits for large audiences. Examples include the Black Smoker in the Hall of Planet Earth in the American Museum of Natural History in New York City, and the Seafloor Science exhibit at the Ocean Institute in Dana Point, CA. Additional efforts in this arena include collaborations with the Birch Aquarium at Scripps and the California Science Center, where R2K members have been aiding development of deep-sea mid-ocean ridge exhibit components. Such efforts provide excellent opportunities to share the excitement, process, and results of R2K research with large cross-sections of the public

<u>Networks:</u> Collaborations between networks is an effective way to broaden the reach of existing projects and materials. The TXESS (TeXas Earth and Space Science) Revolution is an NSF OEDG project that helps a large network of teachers build a solid foundation in Earth and ocean science by providing up-to-date information

through guided inquiry activities and lectures delivered by science experts. The TXESS Revolution project invited Ridge 2000 to share educational resources (i.e., FLEXE) and science presentations as part of their teacher professional development academy on Extreme Environments and Extreme Events. R2K E&O has pursued similar collaborations with several COSEEs, helping disseminate ridge-related resources and materials through the COSEE network.

Future directions - What are the R2K community's hopes for E&O?
It is the intention of our working group to explore and prioritize potential fruitful avenues for future R2K outreach. Suggestions are being gathered using the provided wiki and these include ideas such as using the Podcasts, Field Guides, and LifeDesks (content management platform) tools and resources of Encyclopedia of Life (EOL) as well as YouTube and GoogleOcean to capture and disseminate R2K discoveries and imagery; authoring a series of public audience magazine and journal articles highlighting R2K science, technology, and discoveries; creating/compiling hands-on labs and lessons for teachers and disseminating these through channels such as DLESE and TOS; and using the arts to communicate to wider audiences. The working group will also explore ways to collaborate with existing programs/resources from marine education partners (e.g., OOI, COSEE, NOAA, Smithsonian's Ocean Portal). Finally, the group will begin to identify members of the R2K community interested in implementing such projects as well as potential funding sources for projects.

The Working Group Members
Liz Goehring - Liz has served as the Ridge 2000 Education and Outreach Coordinator since 2001, initiating an EPO program for the R2K community that built upon and complemented existing outreach efforts. As coordinator, she has focused on creating programs that multiple R2K researchers could contribute to without having to create and fund individual efforts and on developing collaborations and partnerships with formal and informal education and outreach networks to leverage efforts and have a broader reach. Four major programs developed include a Distinguished Lecturer Series (DLS) – targeting academic institutions lacking marine science programs, Student Experiments at Sea (SEAS) – a pilot program to promote authentic inquiry in middle and high school science classes, VentureDeepOcean.org (VDO) – a public website featuring the research discoveries of the R2K community, and From Local to EXtreme Environments (FLEXE) – a web-based science education program developed in partnership with GLOBE (www.globe.gov). Other outreach efforts have included coordination of support to various Informal Science Centers such as the Ocean Institute in CA, serving as co-editor for a special issue of Currents on Deep Hydrothermal Vents, helping initiate the formation of an R2K image bank for research and public use, and assisting with the coordination of R2K involvement in two IMAX films – Volcanoes of the Deep Sea and Aliens of the Deep.

Véronique Robigou – Véronique has been involved in a multitude of mid-ocean ridge, ocean and earth sciences E&O since 1994. She created, implemented, and directed professional development programs for K-12 teachers (REVEL Project), and spearheaded the development of offshore-onshore websites to entrain students and teachers to experience sea-going research and exploration (first REVEL website 1996). As director of an NSF-funded COSEE center she collaborated with scientists interested in augmenting their E&O communication skills and taught courses to graduate and undergraduate students that are eager to communicate their research in K-12 settings, as well as practice teaching in classrooms and collaborate with K-12 science teachers. She contributed to and or hosted media programs such as the JASON Project (1994), NOVA PBS show (1999) and UWTV live-stream programming (2005) from the seafloor. She has developed curriculum in support of museum exhibit (AMNH Education department) and contributed visuals incorporated into museum exhibit (AMNH 1998-1999). She is now working on integrating the rigor of science with visual art to share science stories with the public.

Kathy Ellins – Kathy is the program manager at the Institute for Geophysics at The University of Texas at Austin. Although her early training focused on hydrology, marine geology and oceanography, she currently specializes in geoscience education. For more than ten years she has provided K-12 professional development in Texas to science teachers, including through an NSF-sponsored Opportunities for Enhancing Diversity in the Geosciences project, the TeXas Earth and Space Science (TXESS) Revolution, which she leads. Other projects include Water Exploration, a Web-based education program for Texas high school students developed with funding from the Texas Water Development Board and Earth Systems Science: A Key to Climate Literacy, led by Tamara Ledley (TERC) and sponsored by NASA. Active in national Earth science education reform, Kathy has served on the U.S. Science Advisory Committee (USAC) for the Integrated Ocean Drilling Program (IODP), the IRIS Education Committee and participated in the development of the Earth Science Literacy Principles. She is interested in collaborating on projects that integrate the outcomes and products of E&O efforts of the different geoscience programs and consortia (e.g., R2K, IRIS, MARGINS, etc.) to create a lasting legacy of rigorous K-16 Earth science curriculum materials.

Liz, Véronique and Kathy will prepare and co-lead discussions of the E&O working group, and help prioritize E&O goals as set by the R2K community.

Ellen Kappel - Ellen comes to the R2K E&O group without the traditional background in E&O (however, her scientific background is mid-ocean ridge tectonics). As a program manager for the Ocean Drilling Program (more than 10 years ago), Ellen supported lecture series, graduate fellowships, brochures for many audiences (but generally not K–12), educational CD-ROMS, and other E&O projects. In many cases, she provided the ideas and was the primary contributor. In her current capacity as Editor of Oceanography, Ellen's forays into E&O have been to support new initiatives related to the magazine (see www.tos.org/oceanography) and its sponsor, The Oceanography Society. However, most of those initiatives are related to undergraduate and graduate education. For example, Ellen launched a "hands-on oceanography" column and magazine supplement related to that concept, and she has recently started a "career profiles" column (the theme is: "there IS a good life outside of academia"). With her Geo Prose hat on (Ellen's company), she has worked as editor for several projects related to geoscience E&O (e.g., Earth Science Literacy Initiative, many IRIS projects), but they were not her own initiative. Ellen excels at pressing people into action to help produce products, editing the language, and taking a product to its completion. She is happy to contribute ideas to the E&O working group and contribute to the paper after the meeting. If there are opportunities to collaborate on E&O projects in the future, Ellen is very willing to participate.

Tracy Barbaro – Tracy Barbaro is the Project Coordinator for Learning + Education Group of the Encyclopedia of Life. Tracy focuses on outreach, the development of tools and resources to help educators and learners utilize the species content from the Encyclopedia of Life and facilitating the development of educational partnerships. She is exploring ways to communicate and improve the public understanding of science through social media and interactive platforms. The Encyclopedia of Life (EOL) is an unprecedented global partnership between the scientific community and the general public with the goal to make knowledge about all the world's organisms freely available to anyone. EOL is currently undertaking a Marine Theme, coinciding with the Census of Marine Life. EOL is aiming to promote synthesis and dissemination of marine biodiversity information online worldwide and anticipates compiling information on 90% of marine species through 2013. We hope to leverage EOL's global scale and broad scope to help the scientific and conservation communities address several major questions including major patterns of evolution and biogeography among the major marine groups.

Christy Herren - Christy, a biological oceanographer by training, currently views herself as a scientist-educator "hybrid" with one foot perched delightfully in each exciting world. After a research postdoctoral position at MBARI, she transitioned to become part of diverse team with COSEE Ocean Systems team at the University of Maine. COSEE OS was established to research and design highly flexible and engaging online tools that better enable individuals to understand the relatedness of biological, geological and geochemical phenomenon. COSEE-OS is one of numerous NSF-funded Centers for Ocean Sciences Education Excellence (COSEE) with a mission to help scientists translate their research stories to broader audiences in order to improve public awareness and engagement in ocean sciences. Since fall 2005, COSEE-OS has investigated issues in educational research that pertain to pedagogy, practice, and the learning process. User feedback has reinforced the desire for interactive products and processes that highlight fundamental concepts as well as their "big picture" connections. As a result, COSEE-OS is creating and evaluating multi-media tools that both highlight basic concepts and can be readily applied to other disciplines. Our team hopes to find innovative ways to engage R2K scientists and related investigators to develop more effective tools for education and outreach. Indeed, if NASA can create materials that make people feel like they have visited other planets, why can't the same be accomplished for the hydrothermal vents here on Earth?

Indeed!

The role of primary consumers in models of ecosystem processes at hydrothermal vents

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Woods Hole Oceanographic Institution

Primary consumers play a critical role in ecosystem processes at deep-sea hydrothermal vents through the top-down regulation of chemoautotrophic bacteria, which produce biomass with the energy from the oxidation of reduced chemicals in hydrothermal fluids. Morphological descriptions and geochemical analyses indicate that grazers, such as gastropod limpets, are primary consumers that feed on free-living bacteria at hydrothermal vents. Gastropod limpets are some of the most abundant and diverse endemic vent species and can comprise as much as 85% of the heterotrophic biomass in hydrothermal vent communities. Thus, the biomass of primary consumers reflects, to some degree, the biomass produced by free-living chemoautotrophic bacteria and could be used to constrain or validate models of net ecosystem productivity at hydrothermal vents.

We aim to continue to resolve the source of variation and trophic dynamics at the base of the food web to refine models of energy transfer and nutrient cycling in hydrothermal vent ecosystems. We used a combined approach of molecular identification of gut contents and tissue stable isotope analyses to examine the variation in the diets of four co-occurring gastropod limpets at five diffuse-flow hydrothermal vents at the East Pacific Rise. Our results indicate that limpets feed on chemoautotrophic bacteria, but the diets were different among species and some diffuse-flow vents. However, the differences in the carbon stable isotope values fit with the expected carbon fixation pathways of the different bacteria identified in the gut contents and provide new insights to explain the variation in stable isotope values among primary consumers at hydrothermal vents on other mid-ocean ridges. The next steps will be to determine the rate of consumption (i.e. grazing) and the proportion of the diet formed by primary producers (i.e. chemoautotrophic bacteria). Together with measurements of the flow and composition of hydrothermal fluids and the characterization of microbial communities, a better understanding of primary consumers will further improve models of ecosystem processes at hydrothermal vents.

Degassing During a Seafloor Eruption along the Mid-Ocean Ridge: Helium, Argon and Carbon Isotopes in Basalts from the East Pacific Rise Integrated Study Site

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3. SOEST, University of Hawaii

The degassing of basalts and the injection of volatiles into hydrothermal systems are of central importance to mid-ocean ridge science. Virtually all ridge basalt magmas degas as they ascend through the oceanic crust because they are typically saturated or oversaturated with carbon dioxide. An unknown amount of the degassed CO2 is ultimately incorporated into hydrothermal vent community ecosystems through biochemical reactions. The composition of the basalt substrate and its volatile makeup also influence hydrothermal fluid compositions and the locations of vent communities.

We address basic questions about the linkages between degassing and ridge volcanic and seismic activity. We are measuring helium, argon and carbon isotope compositions, and He, Ar and CO2 concentrations, in the vesicles of basalt glasses from the 1991-1992 and 2005-2006 eruptions at the RIDGE 2000 ISS on the East Pacific Rise. These data can be used to relate volatile degassing to magma evolution and emplacement. The recent eruptions offer an opportunity to study magma recharge, to quantify the amount of pre-eruptive and syn-eruptive degassing, and to evaluate the extent to which mantle carbon may be incorporated into hydrothermal fluids and ultimately into seafloor ecosystems. The questions we address are:

1. What were the relative roles of pre-and syn-eruptive degassing during the EPR eruptions? How much CO2 was lost prior to versus during the eruptions?
2. Was there a transition from closed-system to open-system degassing? For example, are there systematic spatial variations in vesicle13C and 4He/40Ar*, or temporal trends in lavas dated by the 210Po-210Pb method?
3. Is there a relationship between gas contents and 210Pb-226Ra disequilibria? If so, can this constrain the mechanism and timing of gas loss?
4. Do the 13C and CO2/3He measurements provide evidence for direct volatile injection into the seafloor hydrothermal system?

Four Po-dated samples from the 1991-1992 eruption have been analyzed for He isotopes and He concentration in triplicate. The analyses were carried out by crushing to release He in the vesicles, by melting of the remaining crushed powders to obtain the “dissolved’ He concentration, and by melting of glass chunks to verify the He budget from the sum of crushing plus melted powder. All of the 1991-92 samples have the same 3He/4He (8.5 ±0.05 RA) and the same total He content (20-22 μcc/g). Our measured 3He/4He is similar to those previously reported by Gregg et al. [2000] for lava pillars from this area. Notably, our samples show a variation in the vapor-melt partitioning of He between vesicles and glass (Figure 1). This variation appears to show a trend with time, using the 210Po-210Pb eruption dates from Rubin et al. [1994]. The current data set is small, but it does suggest that the initial phase of the eruption involved magma that had the same amount of total gas as later stages of the eruption, but which was enriched in its vesicle gas proportion. We speculate that the eruption occurred either from a magma lens that had experienced some upward enrichment in the extent of vesiculation, or that ascent rate to the seafloor varied during the eruption, with the initial lava ascending more slowly and thereby having more time for vapor-melt re-equilibration.

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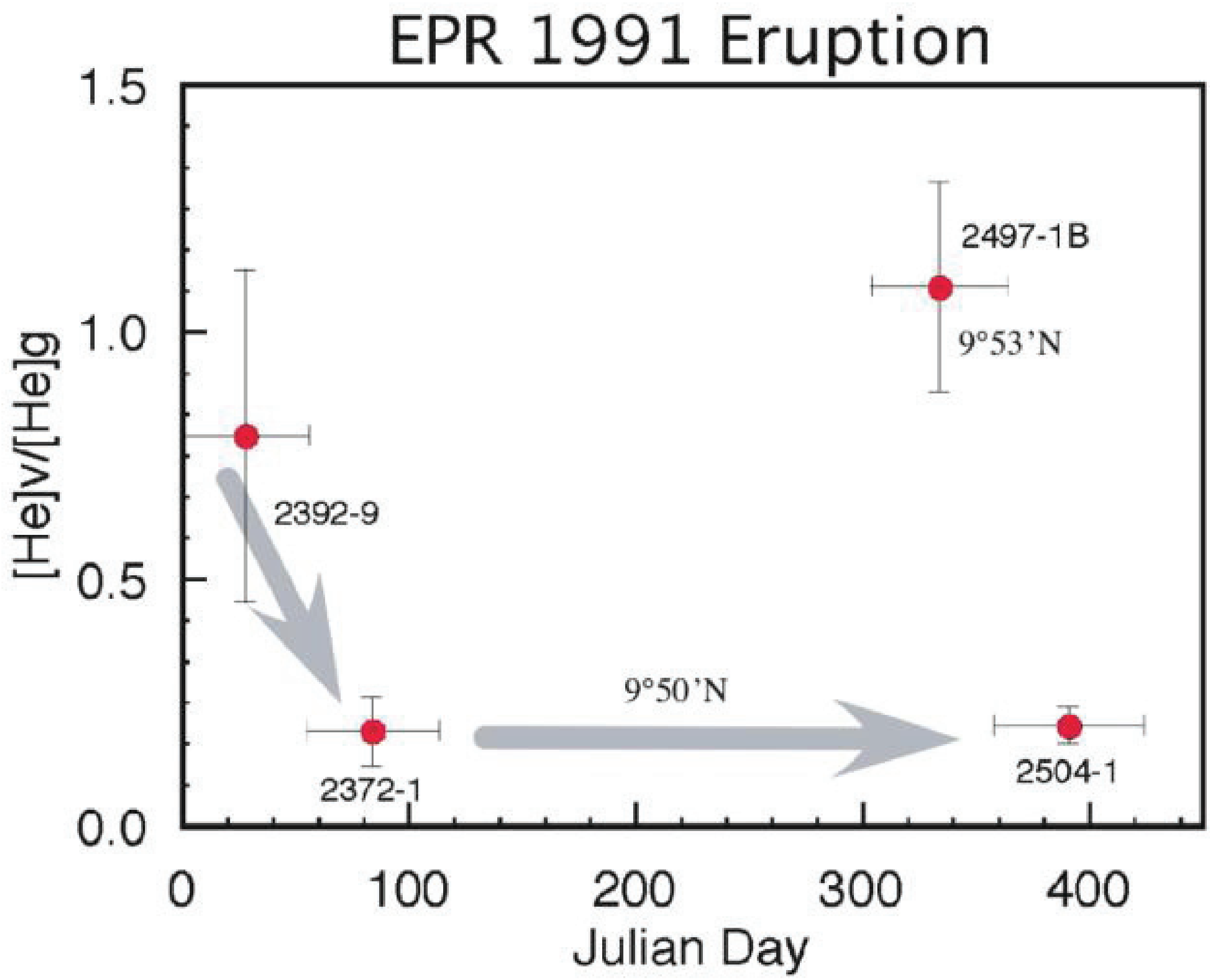

Modeling mantle melting at mid-ocean ridges

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A self-consistent "bottom-up" geodynamical model that combines thermal and petrologic models has been developed to investigate ridge processes. Specifically, mantle flow and thermal models are used in conjunction with the mantle melting model of Kinzler and Grove (JGR, 1992a, b; JGR, 1993) and the fractional crystallization model of Yang et al. (Contrib. Mineral. Petrol., 1996). Combining fractional melting and crystallization models with mantle thermal models quantifies both the termination of melting and the onset of crystallization. Outputs from these models include physical parameters such as crustal thickness and the major element composition of the extruded lavas. We constrain our model using geophysical data (e.g., seismic and gravity) and major element geochemistry data.

This modeling technique has extensive applications for studying ridge processes and takes advantage of both geophysical and geochemical datasets. Some topics we are currently investigating include:

1. Constraining local/global variations in mantle potential temperature
2. Constraining local/global variations in mantle source composition
3. Predicting the shape of the mantle melt region
4. Tracking mantle melt compositions from depth and exploring melt migration through the mantle (e.g., What part of the melting region is tapped? Which melts make it to the surface? Where are the melts likely to stall?)
5. Exploring the processes that affect the melt as it fractionally crystallizes in the crust (e.g., hydrothermal cooling)

To date, we have used this approach to investigate the shape of the melt region and resultant major element and crustal thickness variations associated with transform fault offsets and examined the specific example of the segmented Siqueiros transform fault (Gregg et al., JGR, 2009). We are also utilizing the model for a global ridge study in which we investigate variations in mantle potential temperature and source composition at both the local (segment-scale) and global scale.

Chimney Time Series: A Spatial-Temporal Record of Hydrothermal System Response to a Full EPR Eruption Cycle

Rachel Haymon
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Two well-documented volcanic eruptions of the EPR ISS (in 1991-92 and 2005-06) bracketed a full volcanic/hydrothermal cycle, and made it possible for the first time to document a complete cycle via time-series observations and sampling. Hence EPR ISS hydrothermal chimney time series samples are a unique natural seafloor experiment on how chimneys grow and petrologically encode into the geologic record a complex spatial-temporal hydrothermal response to a fast-spreading ridge volcanic cycle.

EPR chimney evolution began with formation of "proto-chimneys" (poorly-cemented mineral aggregates a few cm tall) on new basalt flows in 1991. This was followed by subsequent growth in 1992-2005 of 7-10 m high mineral edifices encased by tubeworms and other organisms, and culminated with volcanic modifications of the chimneys that survived and petrologically recorded the 2005-06 eruption. Changes with time in chimney minerals, porosity, morphology, and substrate characteristics produced chemical and physical evolution of chimney habitats reflected in the faunal succession of organisms inhabiting the chimneys.

Before, during, and after the volcanic eruptions, dramatic changes in hydrothermal conditions were recorded by changes in chimney mineral assemblages, textures, growth features, and fossilized organisms. Changes in the redox state of vent fluids following eruptions were recorded by change of chimney minerals from lower to higher oxidation state. Changes in fluid temperatures and densities (reflecting changes in depth of hydrothermal circulation, phase separation, and near-critical fluid expansion) shifted chimney mineral stabilities/solubilities and altered hydrothermal flow dynamics in ways recorded by chimney mineral composition and growth features. Ponding, draping, and drainback of lava around standing chimneys produced previously unrecognized morphologic and petrologic features of the surviving chimneys.

Because chimney petrologic features continuously recorded hydrothermal system changes between discrete fluid sampling and vent measurements, the chimneys illuminate what transpired during time gaps in other EPR vent observations (for example, the EPR ISS chimneys record fascinating short-term oscillations in redox and in subseafloor hydrothermal fluid-seawater mixing).

Spatial complexity of the hydrothermal system was evident. Some vents never recorded low oxidation states; some evolved from low to high oxidation states; and others flipped back and forth between these paths. While some chimneys show oscillations in seawater entrainment, others do not. Is this produced by seismicity? Or by oscillations in fluid density (i.e., buoyancy) as fluids penetrate into subcrustal regions where threshold P,T conditions are met for phase separation or fluid expansion near the critical point of seawater? How does seawater entrainment affect organisms living on and within chimneys and within the seafloor? Answers are likely to lie in linkages to other EPR ISS datasets as clues from chimneys are matched in space and time with other observations.

Hydrogen limits on growth and maintenance energy estimates for thermophiles and hyperthermophiles

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We are interested in biogeochemical processes in deep-sea hydrothermal systems and can contribute to the integration and synthesis of ideas related to in situ bioenergetics and habitat modeling. At appropriate temperatures and pHs, life exists where the metabolic energy available for growth exceeds the maintenance energy costs of living in that environment. Existing bioenergetic models have little data for metabolic processes above 50°C, some key modeling assumptions require refinement, and the physiological bases for maintenance energy variations in thermophiles needs study. Our field and laboratory work with hyperthermophilic methanogens from the Endeavour Segment and Axial Volcano on the Juan de Fuca Ridge shows that they are H2 limited below 10-20 μM, which generally explains their distribution patterns at several global vent sites. H2 deficits are compensated for through commensal growth with H2 producing hyperthermophilic heterotrophs that likely obtain their energy from nearby mesophilic sources. In pure culture studies, CH4 production rates per cell increase significantly towards the physical and chemical limits of their growth suggesting that maintenance energies vary within an organism with environmental conditions that must be accounted for in habitat models. These data are needed to model biogeochemical processes such as CO2 fixation in the deep sea, sulfur and metal fluxes, and carbon and nitrogen flow through trophic levels.

Modeling the bioenergetics of metabolism above 50°C requires a better understanding of maintenance energy costs that will require the input of microbiologists, fluid geochemists, and bioenergetic modelers. Our future research includes studying thermophiles and hyperthermophiles with varying metabolisms to measure maintenance energy costs, account for differences in these costs due to physiology, and ground truth our laboratory findings with field studies. Another goal is to concomitantly analyze the metabolites of these organisms using RAMAN-LIBS to establish biosignatures for in situ sensor development.

Linking Stress Changes And Hydrothermal Activity During A Non-Eruptive Spreading Event

Emilie Hooft
University of Oregon

A recent development at the Endeavour Integrated Studies Site (ISS) is the first observation of a multi-year non-eruptive spreading event. This consisted of a 6-year sequence of seismic swarms that was bookended by the two largest swarms in 1999 and 2005 and was followed by a pronounced drop in background seismicity. Although none of the swarms were accompanied by a seafloor eruption, they clearly have a magmatic component. We interpret this sequence as a 6-year non-eruptive spreading event that cumulatively ruptured most of the segment and relieved extensional stresses.

Integration and synthesis at the Endeavour ISS.
This is the first multi-year episode of intrusive plate spreading to be observed at any ridge. A unique seismic network that we deployed around the vent fields from 2003-6 recorded the seismicity associated with the latter part of this spreading event. To infer the associated spatial and temporal patterns of crustal stress changes we are applying rate-state modeling to seismicity rates and are using studies of b-values. We are also determining the spatial and temporal patterns of upper crustal seismic anisotropy and whether this relates to changes in crustal stress. To understand the influence of crustal stress changes on hydrothermal flow, we will integrate our observations of stress changes and crustal anisotropy with hydrothermal temperature and compositional perturbations. We will also combine our determinations of stress changes associated with the 1999-2005 non-eruptive spreading event with observations of regional borehole pressure perturbations to constrain the strain associated with extensional events.

Earlier this summer we submitted a paper to G3 that integrates a seismic analysis of the late February 2005 earthquake swarm with hydrothermal responses and hydrologic pressure perturbations to understand the tectonic and magmatic processes occurring during this seismic swarm. The spatial and temporal seismicity pattern is complex and located around the Endeavour – West Valley OSC. The start of the main episode of the swarm initiates a hydrologic pressure response at distances of 25-105 km that we attribute to a magmatic intrusion at the northern tip of the Endeavour axis. This is consistent with a RIDGE 2000 event response cruise that found no evidence of a seafloor eruption. While the amplitudes and signs of the hydrologic pressure perturbations imply that this intrusion is the main driving process for the seismic sequence it is largely aseismic. We infer that the intrusion changes stresses on the opposing limb of the Endeavour OSC causing tectonic deformation and giving rise to diffuse seismicity in the southwest Endeavour Valley as well as six larger strike-slip events. There may also be additional dike propagation from the West Valley segment to the south. These results are consistent with the eventual decapitation of the northern Endeavour ridge axis by the West Valley segment. Lastly we infer that a hydrologic pressure pulse diffuses away from the main magma intrusion and triggers seismicity beneath the Endeavour vent fields and perturbs flow at a diffuse hydrothermal vent in the Mothra field.

Integration with the EPR ISS.
Ridge 2000 Integration and Synthesis also involves inter-comparisons between sites. At the Endeavour our seismic data in combination with SOSUS and the borehole pressure records will provide strong constraints on the stress and strain changes associated with a non-eruptive spreading event. At the EPR, Maya Tolstoy and her collaborators have recorded the seismicity associated with an eruptive spreading event in 2005-6. We intend to work with the EPR team to compare these two contrasting spreading events. One key issue is to determine why there were eruptions at the EPR but not at the Endeavour. If stressing rates are higher on the EPR as evidenced for example by comparisons of the patterns of focal mechanisms, temporal and spatial trends in b-values and stress changes and the levels tidal triggering, we might infer that higher volatile overpressures play a role in eruptions at the EPR. Alternatively, if the characteristics of the seismicity are similar, the different volcanic styles may be a direct result of differing average upper crustal densities.

Techniques for evaluating the variety and rates of biogeochemical processes in seafloor hydrothermal systems

Jennifer Houghton
Rhodes College

Within the shallow subsurface of hydrothermal systems, microorganisms simultaneously depend on and alter their mineral and fluid substrates. The products of these biogeochemical interactions alter the nutrient flux available for water column processes, ultimately becoming incorporated into the world's oceans. Key to these subsurface processes are biological and chemical diversity and reaction rates, which have been studied in the field, with models, and by recreating systems in the laboratory.

Field studies still provide the clearest snapshot of biogeochemical processes in seafloor hydrothermal environments. New in situ technology has allowed the collection of high resolution datasets monitoring chemical and heat fluxes (Ding et al., 2001; Tivey et al., 2002; Ding et al., 2005). Detailed studies of microbial communities on fine spatial scales linked to mineralogical zonation within chimney deposits (Kormas et al., 2006; Schrenk et al., 2003) inspired new studies to characterize colonization succession (Page et al., 2008). Recent findings from field studies, however, indicate additional levels of complexity, including the realization that current methods may vastly underestimate true diversity (Huber et al., 2007). Likewise, the chemical complexity in time and space is correspondingly underestimated (Luther et al., 2008) and yet is critical to accurate descriptions of biogeochemical processes due to rapid rates of microbial metabolism over small spatial scales. In addition, meta-analysis of these field data is hindered by asynchronized biogeochemical datasets and the lack of a centralized or cross-referenced data repository. These issues also impede the calibration of biogeochemical models incorporating microbial activity.

To constrain habitat regimes for microorganisms in the primarily inaccessible regions of hydrothermal systems, reactive transport models linked to calculations of energetics have been successful (Tivey, 2004; Shock and Holland, 2004). Models have been constructed to describe generic systems and predict microbial metabolic niches (McCollom, 2000) and recently to describe specific systems for which microbial surveys were previously conducted (Houghton and Seyfried, in press). However, geochemical models are limited by their thermodynamic assumptions, including both the equilibrium constants at in situ conditions (Foustoukos and Seyfried, 2007; Luther et al., 2001) and the relative reaction rates of key redox reactions (Foustoukos et al., in review). Careful evaluation of chemical speciation at both equilibrium and disequilibrium conditions on time scales relevant to microbial metabolic rates will continue to be critical in transforming modeling techniques from generalized to specific predictive tools for biogeochemical processes

Experimentally simulating biogeochemical processes is a blend of traditional techniques used to determine kinetic and equilibrium behavior (Seewald, 2001) and traditional enrichment culture techniques used to evaluate microbially-mediated reactions and rates in monoculture (Vetriani et al., 2005; Holden and Adams, 2003). Recent work in this lab is focused on determining chemical and physical modifications caused by mineral-precipitating microbial communities using both open-system experimental observations and corresponding reactive transport modeling to quantify changes in permeability and chemical fluxes along sharp thermal gradients. The rates of microbially-mediated reactions under non-ideal growth conditions simulating subsurface hydrothermal environments are critical data necessary to begin evaluating interspecies reactions within subsurface communities and biofilms.

Changes in the formation of axial volcanic edifices in response to changes in magma supply

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The spatial distribution and abundance of volcanic edifices (>40 meters high) along normal mid-ocean ridge (MOR) systems (i.e., those where only spreading generates magma) have a well known variation correlated with axial morphology. Along fast-spreading MORs, volcanic edifices tend to form near the ends of tectonic ridge segments where the lithosphere is brittle and magma can escape (Bohnenstiehl et al. 2008; White et al. 2000, 2002, 2006). In contrast, volcanic edifices along slow-spreading MORs tend to form around the center of a first or second-order axial valley segment (Cochran 2008; Smith and Cann, 1992).

However, spatial and size distributions of volcanic edifices along ridges with an elevated magma supply differ from distributions observed at normal ridges spreading at the same rate, suggesting that magma supply plays a fundamental role in controlling their formation. Understanding how volcanic edifices form in response to changes in magma supply alone is possible along ridges of similar spreading rates, variable crustal thickness and mapped extent of elevated magma influence. Recent geophysical and geochemical studies along the Galapagos Spreading Centers (GSC), Juan de Fuca Ridge (JdFR), Southeast Indian Ridge (SEIR) and the Valu Fa (VF) and Eastern Lau Spreading Centers (ELSC) constrain the extent and amount of extra magma supply. At these places, it is possible to control for the effects of spreading rate, making it possible to elucidate the formation of volcanic edifices from changes in magma supply and axial morphology.

To understand and identify the spatial and size distribution of volcanic edifices along ridges with an elevated magma supply, we applied a modified version of the closed contouring algorithm used in Bohnenstiehl et al. 2008 to the GSC, JdFR, SEIR and the VF and ELSC. The new contouring algorithm includes a modified version of Hiller's (2008) "Delimiting and isolating seamounts" method for picking the base of a seamount by identifying slope breaks along the seamount elevation profile. This method improves the ability of our algorithm to estimate an accurate volume and height. Volcanic edifices greater than 40 meters in height and a long to short axis ratio of < 2.5 were derived from shipboard multibeam bathymetry gridded at 100 meters. For direct age comparison, only volcanic edifices within 0.2 million years from the axis are studied.

Preliminary results from VF and ELSC (top half of figure) follow trends associated with spreading rate, not axial morphology. These results seem to suggest magma supply is not the controlling factor on the formation of volcanic edifices along this back-arc spreading system. It is interesting to note that volume distribution is not tied to abundance distribution, i.e. the same sized volcanic edifices are not forming in the same location along the segment. The abundance percentage distributions along second order segments from the SEIR show trends we expect for axial high segments, even for segments with an axial valley morphology. However, axial high segments directly influenced by the Amsterdam / St. Paul hotspot (AH-HS) have a distinctly different abundance distribution, similar to what we expect for normal axial valley segments (more randomly distributed). In this case magma supply seems to be the controlling factor on the formation of volcanic edifices.

New geochronological constraints on hydrothermal venting at the Endeavour ISS

John Jamieson
University of Ottawa

Hydrothermal sulfides record the history of high-T venting along ridge segments, arcs and back-arcs. The sulfides record evidence of changes in fluid temperature and composition with time, spatial and temporal shifts in venting locations and responses to seismic and volcanic events. However, understanding the full context of this information requires that the relative or absolute ages of the sulfides are known.

We will present new geochronological studies of the hydrothermal sulfides within the Endeavour ISS. Results from Ra-226/Ba geochronology in sulfide-associated barite indicate that high-T venting within the current axial valley was likely initiated <5,000 years ago. Previous geochronological studies of hydrothermal sulfides from the Juan de Fuca Ridge have focused on rates of chimney growth and sulfide accumulation using short-lived isotopes (e.g. Pb-210 (half-life of 22.3 yrs.), Ra-228 (half-life of 5.7 yrs.) and Th-228 (half-life of 1.9 yrs.)) (Kadko et al., 1985; Grasty et al, 1988; Kim and McMurtry, 1991; Reyes et al., 1995). These studies represent snapshots of venting activity over short timescales (<10 years). The examination of processes that occur over the lifespan of an entire vent field require the use of radioisotopes with longer half-lives, and this long-term history is the focus of our work. Radium-226 (half-life of 1,600 years) occurs in high abundances in hydrothermal barite, which precipitates in conjunction with sulfide minerals on the seafloor. Measurements of the Ra-226/Ba ratios of hydrothermal barite provide a chronometer that allows for the determination of the absolute ages of sulfides between ~300 to 20,000 years old. Age calculations of 63 sulfides from Mothra to Sasquatch show a range of ages from present to a maximum of 3,022 years. This maximum calculated age represents a minimum age of venting at Endeavour.

Information on the ages of hydrothermal sulfides and longevity of venting at Endeavour may have profound implications for numerous topics of investigation within the ISS. Specific areas where these data may be applicable for integration and synthesis include, but are not limited to:

- Temporal changes in vent fluid chemistry and fluxes
- Accumulation rates of sulfide
- Episodicity of venting and spatial constraints on past venting activity
- emporal constraints on biological colonization and evolution
- Correlation between hydrothermal venting and the volcanic/tectonic history of the current axial valley

I envisage that these data will be of particular interest to participants in the following Thematic Working Groups:

- Spatial and temporal variation in chemistry and heat fluxes in hydrothermal systems, including chronic plumes
- Seafloor tectonic and volcanic events and responses, including event plumes
- Biogeochemical processes in deep-sea hydrothermal systems
- Crustal controls on magma reservoirs and ocean spreading center magmatism

A poster containing details of this study, including results and methodology, as well as some interpretation, will be on display during the poster session.

Fluid crustal residence time

David Kadko
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There is general agreement that the primary characteristics (temperature, pH, redox state, major element composition) of many high-temperature (black smoker) MOR hydrothermal fluids are produced by reaction with mid-ocean ridge basalt (MORB) at a water/rock ratio (W) near 1 under conditions approaching equilibrium with a secondary mineral assemblage near 400°C at 300–500 bars. Phase separation is responsible for the large changes in chloride and other major elements that have been observed in such fluids. Rock composition can be affected by the degree of prior alteration and can also cause variations in fluid chemistry in some circumstances. Fluid chemistry, as well as biochemical characteristics, should also be affected by the reaction pathway and residence time of fluids within the oceanic crust. For many fluid chemical properties, the high temperature reaction zone overprints the prior history of low-temperature reaction in the recharge zone, so the most important temporal measurement is the time between the onset of high-temperature water-rock reaction and venting at the seafloor. The residence time of hydrothermal fluid (defined here as the time elapsed between being heated to 200°C and exiting the seafloor) should depend directly on the depth of the heat source and the permeability along the path of fluid convection. Measurement of naturally occurring radioisotopes in vent fluids and associated sulfide deposits have been used to constrain the crustal residence time of the hydrothermal fluid from the initiation of high temperature rock alteration. The activity of two isotopes in vent fluids, 210Pb (t1/2 = 22.3 y) and 228Ra (t1/2 = 5.77 y) are used as chronometers for the time that the fluid has resided under high temperature conditions of the crust. Specific to this meeting, I would like to incorporate new radium isotopic data (fluid and rock) from Lau, EPR and Endeavour into collaborative manuscripts with other vent geochemists and biologists.

Heat and chemical flux variability within Main Endeavour Field from 2000, 2004

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The Main Endeavour Field (MEF) has had a split personality since it was discovered. The southern half of the field is regularly observed to be hotter and fresher than the northern half. Differences lessened after the 1999 earthquake event, but the thermal and chemical gradient remains. We examine CTD and MAVS data collected during surveys, designed to intersect the rising hydrothermal plume, conducted with the Autonomous Benthic Explorer (ABE) in 2000 and 2004. By taking subsets of the data over known portions /structures of the field, we attribute fractional contributions to the whole field heat and salt fluxes. Preliminary findings indicate that North MEF contributes ~90% and ~100% of the heat from MEF in 2000 and 2004 respectively. It is clear from this that the majority of the MEF buoyancy flux is from North MEF even though the source fluids from South MEF are estimated to be initially more buoyant than those from North MEF. Within North MEF, ~2/3 of the heat comes from the Grotto, Dante, Lobo area and ~1/4 from Hulk and Crypto. We are currently striving towards a calculation of chemical flux that has predictive capabilities of the source characteristics. With both years, it is possible to determine the intrafield spatial scales that fluxes of heat and salt are being efficiently mined.

The results presented are from the Flowmow and R2K funded Seabreeze research programs. These results will be integral to discussing: influences from multiple sources to the total heat flux, methodology for measuring plume fluxes, site to site variations, relationships between plume magnitude and hydrothermal field size, and plume impacts on the overlying ocean. We look forward to working with others towards the common goal of understanding the physical complexities of hydrothermal plumes.

The Next-Generation of Mid-Ocean Ridge Technology: Developing Vehicles, Sensors, and Autonomy for Advancing Scientific Surveying, Sampling, and Observation

James Kinsey
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Deep submergence vehicles remain workhorses of mid-ocean ridge research and are the primary means for scientists to access the MOR and obtain data, samples, and observations. The duration of the Ridge 2000 (R2K) program has seen the transition to next-generation ROVs and the Alvin HOV will soon undergo significant upgrades. These platforms will continue to provide valuable access, especially for sampling and observation. However their limitations in mobility, endurance, and cost (amplified by the decreasing number of UNOLS vessels and increasingly competitive research funding) prevent them from transforming ocean science and motivates exploring new vehicle technologies.

Last year marked the 10th anniversary of ABE's bathymetric survey of the EPR and the 15th anniversary of ABE's magnetic survey of the Juan de Fuca – two pioneering surveys of MORs and oceanography in general. These surveys demonstrated to the community the potential of AUVs to transform deep ocean science, and, over the last decade, AUVs have evolved from a nascent technology to mature tools for ocean exploration and research. Their survey capabilities include bathymetry, magentics, optical imaging, and exploring and localizing new hydrothermal vents (AUVs have contributed to the discovery of numerous new vent sites over the last decade. In addition, AUVs are used in coordination with HOVs and ROVs to enhance investigations with these vehicles (with data obtained with an AUV often informing HOV or ROV operations within a few hours) and increase the overall cruise productivity. These successes demonstrate the capabilities of AUVs however we have yet to fully exploit the potential of these vehicles to transform MOR investigations and oceanography in general.

Until now, the challenges facing the ocean robotics community have been developing and operating vehicles in the extreme ocean environment. Having met these challenges, we can focus our research on enabling ocean robots to undertake missions previously considered impossible or difficult. Examples include achieving a 1000km mission (essential for surveying large portions of the MORs and observing possible water-column interactions between vent sites); undertaking an extended multi-month (or year) temporal survey of a site (ABE's originally defined mission); further developing the capabilities of these vehicles to operate in extreme regions including the high-latitudes (e.g., Gakkel Ridge) and using AUVs to autonomously respond to events (a compelling link to OOI). Achieving any one of these goals would radically alter how we research the MORs and provide the entire community with a valuable new capability. The technology used by the MOR community has broad impacts throughout the oceanographic community and society in general – for example, pressure tight samplers (developed for hydrothermal vent sampling) and the Sentry AUV were both used this past June to help research the impact of the Deepwater Horizon Oil Spill.
To achieve this next generation of vehicles requires continued exploitation and development of a number of technologies including:

1.Navigation in the Mid-Water Column - Doppler sonars and landmark navigation have significantly improved near-bottom navigation, however, few sensors provide horizontal state measurement in the mid-water column, thereby vitiating our ability to precisely navigate in this region of the ocean. The limited amount of sensors measurements available at these depths implies that model-based state estimators and multiple vehicle navigation will be essential to implementing navigation in this area. Present techniques are sufficient for oceanographic research, however the continually increasing interest in biological and physical oceanography in the mid- water column motivates developing improved navigation systems.

2.AUV Compatible Sensors – Developing sensors to better measure and observe MOR processes has been a key element of the R2K program, however more effort needs to be made to develop sensors possessing the power and size characteristics necessary for deployment on an AUV. This task is essential as any advances in vehicle engineering or autonomy will be fruitless without sensors. Crucial to this objective is the MOR community identifying and prioritizing sensors that have the potential to transform investigations.

3.Optimal Surveying, Advanced Autonomy, and Autonomous Data Processing and Classification – Traditionally, the oceanographic engineering community has relied upon trajectories defined a-priori. The time and power necessary to achieve tasks can be optimized by selecting trajectories based on data obtained in-situ. Combining these measurements with models of vehicle dynamics and scientific processes can provide simultaneous estimates of the vehicle and environmental state, thus allowing for optimal completion of objectives. As AUVs conduct longer duration missions, the need for these vehicles to independently process and classify data will become increasingly important. This capability would allow AUVs to react to events autonomously – altering trajectories or (in the future) obtaining samples. In addition, crucial data could be transmitted acoustically to other AUVs or surface vessels. This capability is also crucial in traditional HOV and ROV operations, where the increasing amount of data obtained essentially saturates scientists at-sea and reduces their to interpret and act on data while still on-station. On-shore data management and archiving is important but data analyzed post-cruise is effectively "too late" with follow-up data and sample collection postponed (often years) until future cruises.

4.Multiple Vehicles – The deployment of multiple vehicles to sites of scientific interest coupled with improved environmental and navigation estimation algorithms increases our ability to effectively search, locate, and study scientific processes. The ability of vehicles to operate in the same region and share information will allow for reductions in the resources (e.g., LBL transponders, high-resolution sensors) necessary for ocean exploration. These advances will significantly alter our abilities to use underwater vehicles in oceanography, and potentially alter ocean exploration strategies.

Achieving all of the above goals is beyond the scope of R2K or any successor program, however, given R2K's history of using new ocean technology to advance it's scientific objectives, technology should be a key component of any future program. The objective should not be limited to technology made available by other programs but to actively fund and foster new technology development crucial to MOR science. The MOR community should rise to the challenge of identifying crucial missing data sets for MOR science and the technology necessary to obtain these measurements. Based on this consensus, the community should advocate and support a long-term effort, both technical and scientific, to develop the necessary technology and implement it in MOR investigations. A crucial criteria in selecting this "Apollo Program of MOR science" must be its application to other fields of science. For example, advancing our ability to measure fluxes would not only benefit MOR science but the developed technologies and methodologies could be applied to enhancing investigations of the role of the ocean in climate change or improving assessment of marine pollution. A program of this size and scope could potentially resonate with NSF programs traditionally not pursued by the MOR community, including cross-cutting programs at NSF. We should aim high – the sea surface (and beyond) is the limit - and develop the technology necessary to understand the MORs and it's interactions with the ocean and Earth as a whole

Reactive Transport Modeling of Biogeochemical Processes at Main Endeavour Field

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TWG – Biogeochemical Processes – In situ bioenergetics and habitat modeling

Chemical and temperature gradients between seawater and high temperature vent fluid incident at the base of the biotic zone serve as driving forces for metabolic reactions of organisms living in this environment. Over the last decade insight into the nature of endmember and diffuse fluid composition and the biological processes that capitalize on and modify these fluids (e.g., Amend and Shock, FEMS Micro. Rev. 25: 175-243) has improved significantly. However, the spatial distribution of these processes and the linkages to surface manifestations of biology are not well constrained.

In our work, we will aim to create a reactive transport model of the Main Endeavour Field (MEF) that integrates fluid flow in porous media with chemical equilibria to predict fluid composition as a function of space and time. These predictions will then be compared to the extensive Ridge 2000 database of information on MEF fluid chemistry which in turn will enable us to provide better constraint on the transport of chemical species.

Modeling of the shallow subsurface will be undertaken with a stepwise approach that investigates transport first, followed by chemical equilibria and kinetic reaction. The initial physical and chemical characteristics of the shallow domain will be performed with Tough2 (Pruess 2004, Vadose Zone J.: 738-746), which simulates heat and mass transport in porous media at high temperatures and pressures. Subsequently, we will focus on computational descriptions of the biogeochemical processes (such as microbial primary production and carbon uptake by macrofauna) that are central to ridge hydrothermal systems.

The resulting computational framework will provide a way to test hypotheses about how perturbations to the system (such as magmatic intrusions and the aftermath thereof) affect the complex web of interdependent chemical and biological reactions to produce measurable changes in vent fluid chemistry (e.g. Lilley et al. 2003, Nature 422: 878-881; Huber et al. 2003, FEMS Micro. Eco. 43: 393-409).

Hydrodynamical models of water column concentrations and fluxes in hydrothermal regions

Bill Lavelle
NOAA/ PMEL

3-d regional circulation models offer the potential for evaluating/estimating the distribution/concentrations and transport of vent-originating chemical species and biota along and off ridges, around and away from active volcanoes, and deposition into their neighboring sediments.

At this stage of measurement availability and model understanding, these models are better suited for forward calculations than inverse calculations. That is to say, given source flux estimates, concentrations and fluxes and deposition patterns can then be estimated; the converse, gaging the value of the heat flux, for example, coming out of any vent or vent field from water column measurements is still some ways off, at least for any flux value accompanied by a precision estimate.

The physical scales of interest in these flux problems vary widely, from flow/transport in an around individual vent chimneys and vent fields, to flow/transport in axial valleys, to flow/transport along and away from ridges or individual active volcanoes. Because the overlying ocean environment is so time variable and source location and fluxes usually so poorly known, the model usage is typically of a process oriented type (e.g. Berdeal et al., 2005) rather than situation directed type. An example of the second is the description of the pathway taken at the EPR by SF6 during the 60 day LADDER experiment (Lavelle et al., 2010). That result required ancillary measurements of currents and hydrography at the site of interest and such measurements are not generally available.

What kinds of problems might yield new insights with existing hydrodynamic models? A longer event plume simulation, as a process model, might look at the conditions or likelihood for the development of multiple megaplumes from a single eruptive event. Imagine a section of ridge of length L being unzipped over time T all during which heat is being added to the ocean at the seafloor. Current models limit T to a very short time interval and simulations to starting plume time scales. Note that problems involving rapidly ascending fluids require the use of models of the non-hydrostatic type.

Diffuse and chronic plume modeling are both ready for further model exploration. No results of 3-d hydrodynamical models for diffuse plumes have yet been published. Some model results for a working group paper of diffuse source distributions of heat, or chemical or perhaps water-column microbial content should now be possible.

The LADDER Project is directed at understanding larval transport between vents sites along the EPR 9-10N segment, and by extension, the transport between ridge segments. The hydrodynamical calculations and physical observations have highlighted new aspects of along-ridge flow and the role of adjacent seamounts in determining time and space scales of larval transport. See ftp://ftp.pmel.noaa.gov/vents/lavelle/animated_cc1plan.gif for an animation of a plume from a steady source at 9°50’N resulting from that modeling work. The methodology developed at EPR might serve as a template for calculations at other ISS sites, at least for transport calculations of a process model sense.

Modeling the rates and constraints of hyperthermophilic Fe(III) oxide reduction

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I am interested in biogeochemical processes in deep-sea hydrothermal systems and can contribute to the integration and synthesis of ideas related to in situ bioenergetics and habitat modeling as well as interactions between life and minerals. The study of hydrothermal vents has led to the discovery of novel hyperthermophile-mineral interactions that influence the biogeochemistry of their environment. Basalt-hosted, mildly reduced and mildly acidic hydrothermal systems appear to be ideal habitats for iron respiring microbes. Our studies have analyzed sulfide samples from the Endeavour Segment and Axial Volcano on the Juan de Fuca Ridge and found that iron reducers are the most abundant hyperthermophilic autotrophs in most samples (Ver Eecke et al., 2009; in preparation). Our pure culture mineral transformation studies show that these organisms oxidize H2 and reduce ferrihydrite (Fe(OH)3) to magnetite (Fe3O4) possibly with a maghemite (Fe2O3) intermediate. By studying the physiology of hyperthermophilic iron reducers and the physical nature of their mineral interactions and transformations, we can begin to model where these organisms are found in the subseafloor and the magnitude of their contributions to biogeochemical processes such as CO2 fixation and mineral alterations.

Modeling the in situ bioenergetics of hyperthermophile-mineral interactions is in its infancy and requires a better understanding of energy generation through mineral reduction and maintenance energy costs. This will require the input of microbiologists, geochemists, and bioenergetic modelers. My future research includes characterizing and modeling factors that influence growth, protein and gene expression analyses, and determining of the types of mineral transformations that take place using M□ssbauer, FTIR, nano-XANES, XRD, and electron microprobe analyses. Another goal of our mineral transformation analyses is to establish sets of biosignatures that could be detected using in situ sensors.

Ver Eecke, H.C., D.S. Kelley, and J.F. Holden (2009) Appl. Environ. Microbiol. 73:242.

Volatiles in hydrothermal fluids help constrain phase separation and water rock reactions

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Volatiles in hydrothermal fluids are important drivers of the location and diversity of biological communities. They are indicators of magmatic linkages, as well as tracers of phase separation and water rock reactions. When these processes are all considered, it becomes clear that straightforward explanations of fluid chemistry are limited, and multiple factors must usually be considered. The limited coverage of fluid samples in space and time further complicate this task. These factors make integration of additional sources of information necessary for the best interpretation of these data. Synthesis of numerical and geochemical models, sensor and geophysical data, broadens and deepens the interpretation of the fluid data.

A series of samples which were collected at Sully in the Main Endeavour Field over the course of several days provide one example of how volatile data support modeling effort. This suite of volatile data can help constrain the possible phase separation scenarios active at the time the samples were collected. These samples show that fluid composition on a single day had a markedly different composition (more brine-like) than the fluid samples collected before and after, which are more vapor dominated. If the two fluids are assumed to be closely related by mixing or phase separation, the volatile concentrations and chloride content rule out mixing scenarios and simple changes in the conditions of phase separation. The data indicate that the fluids were probably produced by a two step process: brine condensation, followed by a near-critical phase separation event. This interpretation meshes well with recent efforts by Coumou et al. which describe this type of phase separation as an unstable mode predicted by numerical modeling. This analysis is only possible because of the high frequency with which samples were collected, which provides additional motivation for the development of more and better in-situ sensors.

There are several other areas where volatile data can be enhanced through integration efforts. For instance, hydrogen and hydrogen sulfide data from MEF can be helpful in discerning details of the water rock reactions in the subsurface. These field data complement modeling work especially well. Modeling results are needed to make meaningful interpretations of the field data, and the field data are needed to constrain the models. We hope to develop collaborations in this area. In addition, the MEF volatile data, including isotopic values for selected samples, can further address questions such as magmatic involvement in the activity between 2000 and 2005, which has been approached through geophysical methods by Hooft et al. Some of these efforts will build on work that is already published, but some can benefit from collaboration during the analysis stage as well.

Modeling Magma-Hydrothermal Processes at Oceanic Spreading Centers

Bob Lowell
Virginia Polytechnic Institute and State University

Mathematical and numerical modeling can help provide an integrated, whole-system quantitative understanding of magma-hydrothermal processes at oceanic spreading centers and make predictions that can guide field investigators to new avenues of exploration. Numerous data sets, particularly from the Juan de Fuca and EPR ISS sites, can be incorporated into, or used to constrain these models, at least partially. To various degrees, these data sets include: (a) time series measurements of vent temperature and salinity; (b) advective heat output and fluid flux measurements from focused venting and diffuse flow (and integrated water column measurements); (c) geochemical data from high-temperature vents and adjacent diffuse flow discharge; (d) petrological data that describe the evolution of the sub-axial magma chamber over an eruptive cycle; (e) seismicity data that may delineate hydrological flow paths; (f) active source seismic data that constrains crustal structure and the size, shape and melt content of crustal and sub-crustal magma bodies; (g) detailed seafloor mapping.

We have recently developed models of magma convection and heat transfer as they link with hydrothermal heat output. These results show that magma replenishment on short time scales (~ years) is required to maintain steady heat output and vent temperature. This work is being continued by exploring convection in high silica magmas, the effect of initial intrusion size and periodic magma replenishment, and the effect of a two-component melt composition. Although these models provide useful, first-order insights into coupled magma-hydrothermal processes, advances in these models can be made if they could be linked with realistic models of multi-component magma convection and the evolution of erupted lavas over time. Additional advances can be made if the magma convection-replenishment models are linked with realistic physical mechanisms of magma replenishment, crustal assimilation, and eruption.

We are also using the NaCl-H2O numerical code FISHES to investigate phase separation processes in seafloor hydrothermal systems. Preliminary results with prescribed basal temperatures show that: (a) vent salinity may vary over time, (b) that vents with salinity both greater than and less than seawater may discharge simultaneously in close proximity, even though the fluid source comes from the same depth, and (c) salinity of the vent fluid represents a mixture between phase separated fluid and seawater and thus may not generally provide a unique solution to the P-T conditions at which phase separation occurs. We are planning to couple models of magmatic convection, replenishment and heat transfer, with FISHES to obtain a more integrated picture of magma-hydrothermal processes together with phase separation, and eventually with vent chemistry.

Distinguishing Arc, Back-arc and Hotspot Affinities in the Northern Lau Basin

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The northern Lau Basin is marked by a complicated pattern of back-arc spreading centers and distinct volcanic cones and calderas adjacent to the Tofua Arc. Recent eruptive activity at West Mata volcano and along the NE Lau Spreading Center has focused special attention on this region. One question that has been difficult to answer is whether these volcanic systems have arc or back-arc affinities. Helium and carbon isotope ratios and C/^{3}He ratios can help to differentiate between arc vs. back-arc influences. Another factor is the Samoan hotspot signal, characterized by high ^{3}He/^{4}He ratios, which has penetrated southward into the northern Lau Basin through a tear in the downgoing Pacific plate. Thus far this Samoan influence has only been seen along the NW Lau Spreading Center some distance from the Tofua Arc, where ^{3}He/^{4}He ratios in the basalts reach values up to 28 Ra (R = ^{3}He/^{4}He and Ra = Rair = 1.4×10^{-6}). True back-arc systems are similar to mid-ocean ridge (MOR) systems with ^{3}He/^{4}He of ~ 8 Ra, δ^{13}C - CO_2) of -4 to -12 ‰, and C/^{3}He of ~1×10^{9}. In contrast, arc volcanoes typically have lower ^{3}He/^{4}He ratios, heavier δ^{13}C of -2 to +2 ‰, and higher C/^{3}He ratios ($\geq 10^{10}$), presumably due to the incorporation of downgoing slab components such as marine carbonates. West Mata, for example, has ^{3}He/^{4}He of 7.3 Ra and C/^{3}He of 10^{10}, indicating strong arc affinities. In contrast, the basalts and hydrothermal fluids recovered from the NELSC have ^{3}He/^{4}He of 8.0 – 8.6 Ra and C/^{3}He of 1 □ 3×10^{9}, typical MOR or back-arc signatures. We have estimated ^{3}He/^{4}He and C/^{3}He values for a number of other volcanoes in the NE Lau Basin, and as might be expected the presence of an arc component increases with proximity to the Tofua Arc. In general these carbon and helium isotopic signatures are a useful tool for distinguishing between these arc, back-arc, and hotspot affinities.

In situ diffuse flow chemistry and discrete bottle focused flow chemistry at 9 deg 50' N EPR

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Using in-situ electrochemical sensors, we mapped the temperature, oxygen and H2S in the diffuse flow environments of the EPR, in coordination with macrofaunal and microbial mapping done by Drs. Lutz, Shank and Vetriani. Unlike Lau Basin, partially oxidized sulfur species (polysulfides and thiosulfate), are rarely detected. Data were collected before and after the 2005-6 EPR eruptions (data were obtained for every year from 2004-8). The S/T ratio rose prior to the eruption at some sites and continued to increase after the eruption; the macrofauna changed from a mussel plus Riftia dominated community to a Tevnia dominated community. S/T ratios at EPR are typically higher than those found at Lau Basin (see white paper by Amy Gartman).

Sulfide in hydrothermal vents was measured by taking a sample and precipitating the sulfide in basic Zn-acetate solution and then frozen. The thawed sample (filtered through 200 nm filters and unfiltered were treated similarly) was treated with HCl to release sulfide from FeS (acid volatile sulfide, AVS) into a trace metal clean basic trapping solution and then sequentially treated with acidified Cr(II) to release sulfide bound to pyrite (reductive dissolution, CRS) in a separate trapping solution. The hydrothermal vents showed increasing dissolved Fe and decreasing sulfide (AVS) concentrations since the eruptions. All dissolved samples yielded significant quantities of CRS up to 11% of the total sulfide indicating that nanoparticulate pyrite is emitted from all vents studied. Similar data were found at Lau Basin vents.

Integrating our chemical data at the same site and between sites with other biological, chemical and geological data should prove useful. The papers below are examples of our first integrations of biological and chemical data.

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Why are mid-ocean ridges segmented? What time-scales apply to the different spatial scales of segmentation?

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Mid-ocean ridge segmentation appears to correlate quite well with along-axis variations in axial depth, cross-axis morphology, basalt geochemistry, intensity of hydrothermal activity and abundance of benthic faunal communities on most spreading centers. Thus understanding the origin of segmentation and its four-dimensional behavior is essential to understanding the linkages between a wide range of processes central to the mission of R2K. Some ideas about why ridges are segmented:

1. Along-axis variations in melt supply?

2. Skewness of mantle upwelling relative to ridge strike?

3. Response of the ridge to migrating over a mantle which has melt-rich and melt-poor regions?

4. Response of newly formed lithosphere to fracture mechanics (crack interaction)?

5. Because they can?

The community would benefit from a synthesis of these ideas, pros and cons, evidence for and against each, and an assessment of what further work needs to be done. Integration of current work on segmentation by Montesi, Carbotte, Toomey, Gregg, Hooft, White, Mutter, Rubin, Salters, Haymon and others would be most interesting and useful.

Physical Properties and Water Content of Volcanic Glasses and Olivines Included in Submarine Volcaniclastic Rocks from North Lau Eruption Sites

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Introduction

Water dissolved as hydroxyl groups or molecular water in eruptive melts plays important role in the viscosity and hence in eruptive style of the ascending magma. Investigation of the water content in refined hyperquenched (basaltic) glasses can provide useful constrains of water contents of the ascending magmas and information on the interaction of magma with seawater. The capability of confocal micro-Raman spectroscopy to determine the total amount of water dissolved in natural and synthetic glasses and minerals has been recently demonstrated [1, 2]. High- T Raman experiments enable us to understand the behavior of water after entrapment and the interface processes between melt inclusion and its host mineral [3].

Several studies of natural and experimentally synthesized/hydrated of olivine show that it can incorporate substantial amounts of OH, which has important implications for rheology, melting behavior and transport properties of mantle.

Proposed/Current Work, Methods and Anticipated Results

1. Measure the physical properties (density, elastic-wave velocity Vp, Vs and moduli, and glass transition temperature Tg) of selected basaltic glasses by Brillouin scattering at ambient and high temperatures.
2. Determine water content in basaltic glasses by confocal micro-Raman spectroscopy. High temperature (1300 oC) Raman measurements will also be carried out to determine the water lost. Results from (1) and (2) above will be compared in light of composition, water content and structure of the basaltic glasses..
3. Physical properties and water contents of olivine crystals in basaltic glasses and volcaniclastic rocks will provide information regarding the nature of OH bonding and interaction of ascending magma with sea water.

Recently, we have synthesized pure forsterite (Fo) and Fo97Fa3 olivine with water contents up to 0.9 wt% water, and have studied the structure, vibrational properties and protonation characteristics by XRD and Raman spectroscopy [4, 5, 6] at high pressures.

Here, we present some preliminary results on four selcted water-containing basalt glasses.

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Abrupt along- and across-axis changes in crustal structure at the Eastern Lau Spreading Center imply rapid changes in mantle composition and mode of advection to the ridge.

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The Eastern Lau Spreading Center in the Lau Basin exhibits large changes in crustal structure, morphology, geophysical, and geochemical characteristics as a function of its separation from the volcanic arc (Escrig et al., 2009; Jacobs et al., 2007; Martinez and Taylor, 2002; Martinez et al., 2006; Pearce et al., 1995). The along-axis changes have been well noted in the above cited studies, but less recognized are equally abrupt changes in crustal properties across the axes of individual spreading segments (Fig. 1). Across individual segments, depth, crustal thickness, morphology, geochemistry, and the nature of segmentation can abruptly change with only a few (<5 km) of incremental spreading. Even neighboring ridge segments separated by only ~8 km non-transform offsets can have long-lived contrasts in the nature of their crustal accretion. A seismic tomographic study (see Dunn and Martinez white paper) indicates that crustal velocity contrasts, interpreted as related to porosity and composition, closely follow the morphologic changes. The abrupt nature of these changes suggests correspondingly large and abrupt changes in the nature of the mantle wedge supplying melt to the axes. These observations suggest that distinct and contrasting mantle domains exist in close proximity and can separately supply even neighboring ridge axes leading to the distinct crustal domains recorded at the seafloor. The concept of broad triangular melting regimes as envisioned beneath mid-ocean ridge axes may not apply to arc-proximal back-arc ridges where mantle wedge viscosity contrasts may span several orders of magnitude as a result of varying water content and strongly influence the mode of advection to the ridge.

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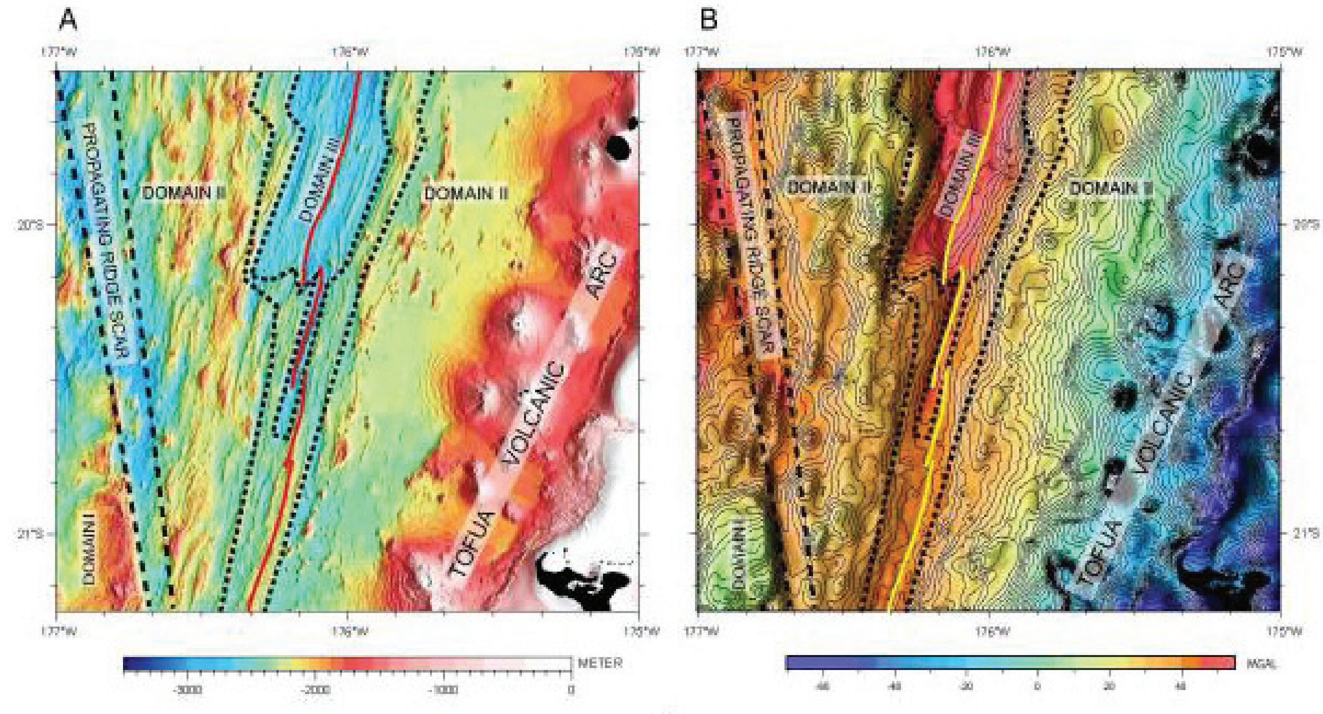
Fig 1. Bathymetry and Bouguer gravity anomalies in the area of the L-SCAN seismic experiment. A) Complied multibeam bathymetry shows rapid transition from shallow complex landforms on the ELSC flanks (Domain II) to a ~500 m deeper flat seafloor dominated by linear abyssal hills (Domain III). B) Bouguer gravity anomalies and isostatic calculations indicate a change in crustal thickness of ~1.9 km across the transition. Domain I is an older terrain west of the pseudofault created by the southward propagation of the ELSC. Fine dashed lines denote the Domain II-III crustal boundaries and the narrow transition region between them.



Observations of the northern, "magma-starved", segment of the East Pacific Rise ISS

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A key assertion about mid-ocean ridges is that the morphological segmentation (depth, cross-sectional shape, distance from ridge offsets) is linked to the supply of magma to the ridge axis. Spreading rate exerts the strongest control on that supply. It is generally presumed that crustal thickness, in turn, may be correlated with spreading rate and magma supply. This is observed with the transition from ulta-slow to slow and intermediate spreading rates, and on slow-spreading rifted ridges (e.g. Dunn et al., 2005). For intermediate to fast-ridges, the role of morphological segementation is well established, as is an apparent link to magma supply (e.g. Macdonald and Fox, 1988). However, despite these correlations, these ridges exhibit apparent striking uniformity in crustal structure and thickness, even when the morphological features change.

The 8°-11°N' ISS on the East Pacific Rise (EPR) spans a full range of ridge morphologies, and several significant discontinuities. From 8°N to 10°N, between the Clipperton and Sequiros Transforms, the first order segment of the ridge is broad in cross-section and shallow, and it includes a substantial axial magma chamber reflection, one that is nearly continuous, except at the second order boundary (OSC) at 9°N. Between 10° and 11°N, and immediately north of the Clipperton, the ridge is relatively deep and has a triangular cross section, evidence for a magma starved segment, although the ridge shoals and broadens to the north. This view is reinforced by the absence of a magma chamber reflection for 70 km north of the Clipperton. We would expect a thin crust under this segment. and thus, it became the type-locality for a "magma-starved" segment on a fast-spreading ridge. Consistent with this model was the identification of more evolved basalts north of Clipperton, compared to those to south. However, unlike magma-depleted segments of ridges spreading at intermediate to slow rates, there is no large rift valley.

Almost all of the research connected with 8°-11°N ISS has been conducted on the magmaticaly robust segment south of the Clipperton Transform, with particular focus on the axis at 9°50'N eruption site. These efforts have resulted in exciting observations extending over 20 years. To a lesser extent workers have conducted research on other portions of segment between the Clipperton and Sequiros Transforms. Far less work has been devoted to north of the Clipperton (10°-11°N).

Subsequent research has revealed several surprises for this latter segment. Barth and (1986) noted that the crust appeared unusually thick near the Clipperton, and pointed out that the presence of Ridge-Transform Intersection highs where the northern segment intersected the transform, perhaps evidence of excess magma on the axis. Based on a seismic refraction survey in 1994, Begnaud and others (1997) noted a low velocity zone in the lower crust beneath the axis. The seismic velocities associated with this zone were not low enough to indicate a large magma chamber, but may have suggested a partial melt zone. In 2003, Alvin dives revealed that relatively large volcanic eruptions had occurred in the months immediately preceding the dives (McClain et al., 2004). The lavas were high in Titanium and Iron (FeTi) basalts. The observation of a volcanic eruption suggests that eruptions do not require a significant (with an AMC reflection) magma chamber. Alternatively it may reveal that the magma chamber has changed since the 1985 reflection survey, or that reflection survey failed to cover the chamber. In any event, appears that the EPR north of Clipperton is not magma-starved, but instead is magma-deficient. It is not known if the more evolved magmas originate at the segment apex at 11°N and flowed southward, or if they evolved at the latitude of the eruption. Regardless, it appears that the crust that results from this magma-depleted segment of the ridge does not appear to be different in structure or thickness that the crust generated on the magmatically robust segment south of Clipperton.

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Carbon assimilation at hydrothermal vents: Quantitative linkages between biotic responses to physico-chemical fluid conditions.

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Abstract: Hydrothermal vents host a diverse and productive biotic community, ultimately supported by the difference of composition between the rising fluid and ocean water. However, the quantitative relationship between fluid characteristics and the physiological response in terms of carbon uptake of key organismal groups such as tubeworms, microbial mats and mussels remains poorly constrained. Our ongoing work aims at establishing such explicit quantitative connections, by linking respirometer measurements of tubeworms, in particular Riftia, and mussels performed under in situ pressure to the geochemical milieu. We are exploring the relationship between environmental factors and biotic response based on a set of laboratory experiments performed at known physico-chemical conditions, in which a single environmental parameter was varied (Girguis and Childress 2006, J. Exp. Biol. 209: 3516-3528). These relationships are then embedded into a mathematical framework that accounts for known buffer capacities of a group of organisms, e.g. for the capability of tubeworms to continue carbon-uptake over an extended period of time even after the delivery of new sulfide has stopped. As a next step, organismal densities then inform the population specific assimilation rates, which vary with environmental conditions that can be measured transiently and in situ (Govenar et al. 2005, MEPS 305: 67-77).

Contributions to Integration and Synthesis: Studies on composition and metabolic capacity of the megafaunal and microbial denizens of hydrothermal vents have been complemented by chemical studies that seek to correlate fluid chemistry with vent biota. However, little is known about the net rates of biogeochemical processes, e.g. primary productivity, in these surficial communities and the above mentioned work contributes to closing this gap. Moreover, distribution and relative importance of the subsurface processes that produce the observed biological assemblage are still not well constrained. Hence, our estimates of fluid controlled net primary production will be interfaced with the work sponsored through a Ridge2000 Postdoctoral Fellowship to B. Larson, which aims at establishing the spatial context for variations in fluid conditions via reactive transport modeling at the Main Endeavour Field site.

H2O, Cl, F and S contents in magmas from Eastern Lau Spreading Center and Valu Fa Ridge: Implications for crustal porosity, magma degassing, hydrothermal chemistry, and mantle melting

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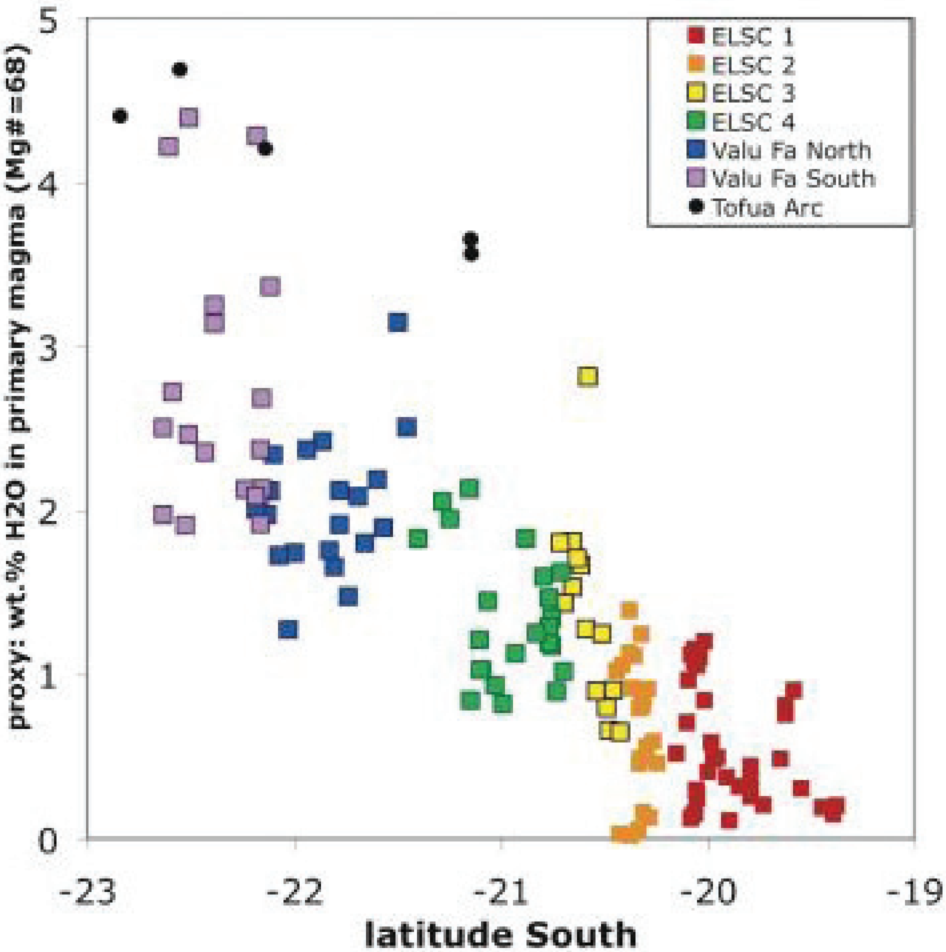
The high H_2O concentration of the Lau mantle source and magmas is perhaps the most influential characteristic of the Lau ISS. High H_2O concentrations influences mantle flow, mantle melting, magma ascent, crustal porosity and magma degassing, including contributions to hydrothermal systems and the life they support.

We have determined H_2O for magmas from Eastern Lau Spreading Center (ELSC) from 19°20' to 20°30'S. Because of degassing, it not possible to determine H_2O contents directly from pillow rim glasses south of 20°30': they are too H_2O-rich. We have combined melt inclusion data for southern Valu Fa Ridge (VFR; 22°30') with our data from the ELSC to look for consistent relationships between H_2O and trace elements, so that we can define a proxy for H_2O content south of 20°30'. The K_2O content of glasses seems to provide the most consistent proxy for calculating magmatic H_2O cotents: better than Ba, Cl and Yb. Proxy H2O contents can be used to calculate the H_2O content of the mantle supplying ELSC-VFR, as done by Bézos et al., (2009) for the northernmost segment of ELSC.

The calculated H_2O contents of primary magmas can be used to estimate depths and extents of vesicle formation if the extent of crystallization as a function of depth is known or assumed. Because H_2O degasses at shallow levels compared to CO_2, it has a much greater ability to create porosity in the crust if its vesicles can be frozen in the rocks. Our preliminary calculations suggest that some vesiculation takes place in ascending magmas beneath the AMC for the Valu Fa Ridge. Magmas ascending from the AMC will also form vesicles in the upper crust. In this case, magmas ascending from a deeper AMC should produce more gas for vesiculation than magmas ascending from a shallow AMC. Magmas ascending beneath the northern ELSC contain lower H_2O contents, so vesiculation should be a much shallower phenomenon and similar to mid-ocean ridges.

It is relatively straightforward to calculate the amount Sulfur lost from the magma based on the S contents expected at a given FeO content. Although the S in the magma of ELSC-VFR occurs almost completely as S^{2-}, even in the southern end of VFR, the speciation of S in the exsolved gas phase is more complicated. It is some combination of SO_2 and H_2S.


ELSC 1
ELSC 2
ELSC 3
ELSC 4
Valu Fa North
Valu Fa South
Tofua Arc
proxy: wt.% H2O in primary magma (Mg#=68)
latitude South
0
1
2
3
4
5
-23
-22
-21
-20
-19

Melt Focusing At Oceanic Spreading Centers

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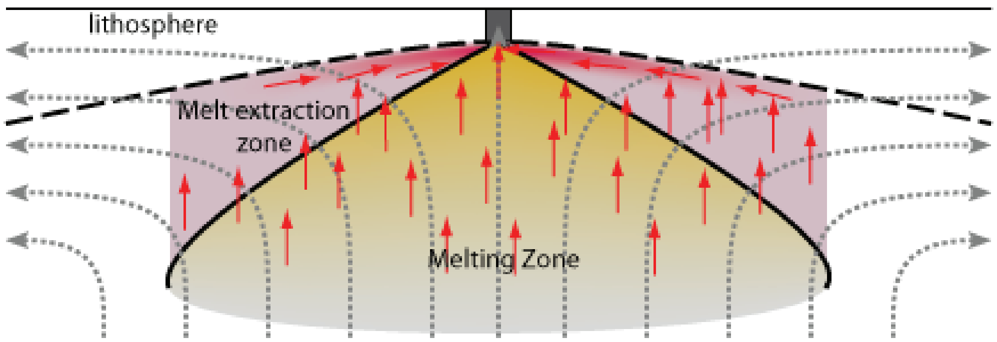
The global geodynamical significance of oceanic spreading centers lies in the fact that they accommodate plate divergence and the vast majority of melt production on Earth. These processes are linked, as melt generation occurs as a result of decompression of the mantle as it rises underneath the spreading center, while melt likely weakens the plate boundary to enable localized divergence. Three fundamental questions related to melt generation and extraction have been the focus of geodynamic studies for decades:

1. Is mantle upwelling essentially passive or active?
2. How does melt focus toward the spreading center?
3. How does along-strike segmentation develop?
4. Multidisciplinary data collected at oceanic spreading centers and laboratory studies have provided new constraints to these questions and motivate the development of integrative geodynamic models of spreading centers.

Tomographic evidence for low residual melt fraction underneath spreading centers and U-series disequilibrium imply efficient melt extraction. Permeability estimates of partially molten aggregates and the possibility of developing localized melt channels, tested by the presence of chemical disequilibrium between peridotites and basalts, permit rapid melt extraction. Rapid melt migration is little influenced by the trajectory of mantle and is expected to follow pressure gradients instead, which, for a mantle viscosity of 1019 Pa s, are clearly dominated by melt buoyancy. Thus, melt migration in the melt generation zone underneath the axis is principally vertical. The low residual porosity implies little density difference in the mantle, and therefore principally passive upwelling. However, porosity-driven convection appears necessary to capture the asymmetry of melting in regions of ridge migration, implying viscosities less than 1018 Pa s (Question 1).

The inference that melt trajectory at depth is essentially vertical cannot be valid near the surface, as it implies little to no melt focusing toward and along the axis. Sparks and Parmentier (1991) proposed that as melt enters the thermal boundary layer at the base of the plate and crystallizes, it forms a permeability barrier. Then, melt migrates along this boundary to collect at the ridge axis. This concept has now been applied to geodynamic models of several segmented spreading centers and can explain crustal thickness variations from ultraslow to ultrafast ridges. Further evidence for this focusing mechanism is provided by seismic evidence for gabbro bodies in the lower crust at several Ridge2000 focus sites and refertilization of mantle peridotites (Question 2).

This melt migration scenario opens the door to addressing Question 3. If focusing along the permeability leads to focusing of melt at certain points along the ridge axis, localized heat input to the ridge can modify the shape of the permeability barrier. Localized magma flux is likely associate to a high density of intrusive features, weakening the axis and facilitating spreading. These two consequences of melt migrations would have the effect of thinning the TBL and increasing melt focusing. Thus, the coupled melt migration and thermal structure system features several positive feedback processes that may result in a segmented magmatic system along the axis. The identification and characterization of this feedback system necessitates the integration of petrological, geophysical, and geodynamical approaches.



What are the Time Scales of Ridge Processes?

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The physical, chemical and biological processes that interact to form mid-ocean ridges, and the oceanic crust they produce, operate at many spatial scales but also at almost the entire range of temporal scales that the Earth exhibits.

Plate motions and large-scale flow in the mantle exhibit the greatest spatial scales of all Earth processes (the Pacific Plate is the largest moving object on Earth) with time scales of 100's of millions of years. Flows in hydrothermal systems are very fast and can change in a matter of hours to weeks to years and associated biological systems vary on a similar range of time scales. Faulting and volcanism in the form of dyking and surface eruption must have a recurrence time on the order of years to decades to be consistent with mass balance calculations, dyke widths and fault spacing. Crustal magma systems must evolve and change over time scale shorter than eruption intervals while the stability of mantle upwelling zones, though not known, are likely to be on the order of thousands to millions of years.

Mid-ocean ridge physical structure is often described as having an ordering that gives rise to the idea of segmentation scales. Temporal scales are unlikely to be randomly distributed and processes operating at ridges may give rise to a few dominant time scales. Cyclical processes, such as tidal triggering of earthquakes and tidal modulation of hydrothermal flow are well documented. Evidence for consistent dike widths and relatively steady state spreading rates suggest a cyclical nature to crustal formation and magmatic processes. Other processes may be quite aperiodic and possibly have power law frequency/magnitude distributions so common in Earth processes. Time series sampling to date has not established the full range of ridge processes temporal characteristics. Technology to monitor deep sea processes with high fidelity over time scales of years has only recently started to become available making the temporal domain a new frontier.

While high-resolution seafloor mapping has provided some sense of the range of spatial scales of ridge processes we presently have little sense of the shape of the spectrum of process time scales or how processes might interact in time. Very little is known, for instance about temporal scales of magma dynamics. Does the magma body change geometry (enlarge) before an eruption then deflate or instead does the liquid fraction progressively increase and fluid pressure rise until the eruption occurs? Seismic time-lapse imaging techniques widely used in the oil industry to track depletion of hydrocarbons in producing fields and more recently for monitoring sub-surface storage of CO_2 can be readily applied to study magma dynamics. R/V Langseth's seismic systems have sufficient resolution and repeatability that repeat surveys can be performed to study changes in shape and properties of the magma body. The 2008 3D cruise to the 9°N area of the EPR where the eruptions took place made the first set of images for this purpose. Monitoring of the ridge to detect any precursors to eruptions such as increases in microseismic activity would help identify the most critical time for a repeat survey and these measurements as well as others could be integrated to build a picture of ridge dynamics.

Future ridge studies should focus on strategies to assess the wide spectrum of time scales of ridge processes and how spatial and temporal scales interact.

The trace element compositional diversity of anorthitic plagioclase: Implications for magma storage and transport in the oceanic crust

Roger Nielsen[1], Adam Kent[1], Frank Tepley[2], Andrew Burleigh[1], Alison Weinsteiger[1], Amy Lange[1] , David Adam[s3]

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3. *United States Geological Survey*

Plagioclase ultraphyric basalts (PUB) represent a class of MORB characterized by abundant (>20%), large (>5mm) anorthitic (>An85) phenocrysts. These lavas are commonly associated with suites of primitive high Al MORB (Eason and Sinton, 2006) that occur primarily at slow to intermediate spreading ridges and close to fracture zones. Our focus is an examination of the range of textures and major and trace element contents exhibited within and between individual phenocrysts of anorthitic feldspars within individual PUB. Although PUB have been described for some time they have not been examined in detail using modern petrological and geochemical tools, and we view them as a potentially rich source of information tha can be used to constrain the nature of ocean crustal magma systems. Our goal is to thus use studies of PUB to probe the dynamics of magma transport and evolution within the oceanic crust, and to document the extent to which the phenocrysts represent a coherent suite of genetically related material, and, the degree to which melt inclusion compositions are the product of entrapment or post-entrapment processes.

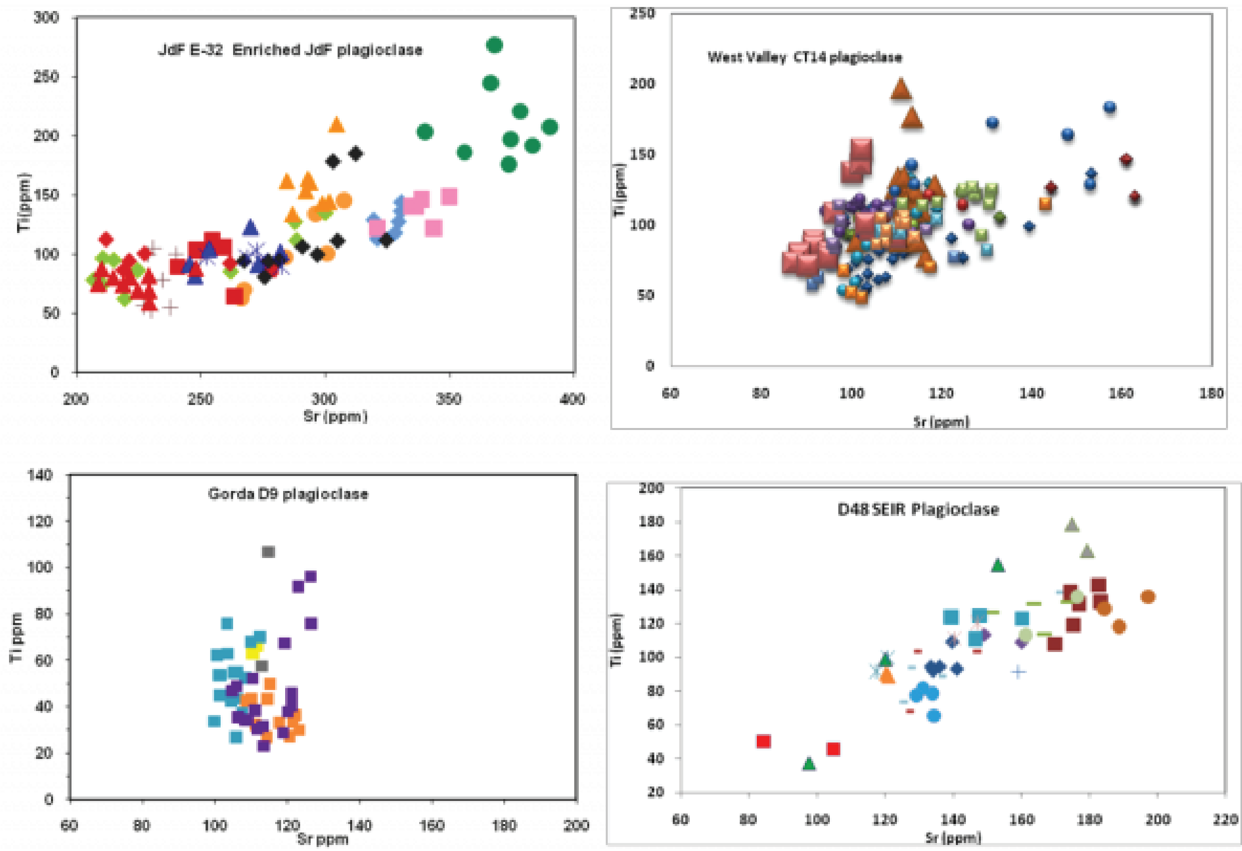
To date, we have collected major and trace element data on feldspars and their associated melt inclusions from several samples from the Juan de Fuca, Gorda, Southeast Indian, and Southwest Indian Ridges (13 individual samples). We see a number of interesting features. The observed range of trace element contents within individual crystals appear to define two distinct trends: 1) patterns are broadly coherent with the individual phenocrysts from a given sample making up components of a composite trend (e.g. JdF E-32 and SEIR D-48) or 2) discordant – with data from individual phenocrysts either trending across a whole sample trend or exhibiting little correlation (e.g. Gorda D-9).

We interpret coherent trends such as D-48 as representative of a collection of phenocrysts from a single genetically related suite of magmas, but where individual crystals have experienced distinct histories within that related magmatic suite. We currently interpret the more incoherent trends to represent collections of phenocrysts from unrelated magmas or the product of diffusive re-equilibration, which would result in re-homogenization of more rapidly diffusing elements (e.g. Sr). To use nomenclature common in more felsic magmas we believe that different systems are characterized by more or less of a contribution from antecrystic and potentially xenocrystic sources. The degree to which the population represents a set of genetically related materials says much about the storage and transport processes. We are currently collecting more data in an effort to see how widespread each of these characteristics is. Further work will also include multicomponent diffusion modeling, Sr isotope analyses via microdrilling and quantitative textural analyses.

To date, with our restricted data set, we see no correlation between trace element characteristics and magma type (e.g. E-MORB vs. NMORB), ridge location, or spreading rate. The variety of patterns suggests that there is an underlying magma transport and storage phenomena that determines the compositional characteristic of specific magmas, and supports our contention that PUB prove a rich source of information about oceanic magma systems.

Sources: Eason, D. and Sinton, J., 2006, EPSL, 252, 423–436.

Nielsen et al. Figure caption. These data represent laser ICP-MS analyses of plagioclase phenocrysts from four individual samples from four different ridges Juan de Fuca (E-32), West Valley - Endeavour (CT14), Southeast Indian Ridge (D48) and the Gorda Ridge (D-9). Different symbols represent analyses from different phenocrysts in that individual sample (i.e. all orange triangles on CT14 plot are from a single phenocryst in that sample).



Microbe-mineral associations within hydrothermal vent sulfides

Heather Olins

Harvard University

Variation in microbial communities and metabolic activities among hydrothermal vent sulfides is unconstrained. There are numerous environmental factors that likely influence the endolithic community, including geochemical and thermal gradients, geochemical flux (e.g. fluid flow), subsurface processes, and chimney age. In such complex systems, it can be difficult to understand the relationship between chemical, thermal, and biological processes. Thus, we also have a limited ability to understand (and predict) microbial biogeography within or among chimneys or between vent fields. Examining microbial ecology in the context of mineralogy may provide a more complete understanding of the diversity, metabolic activity, and overall ecology of these communities. In addition to understanding hydrothermal systems more completely, linking mineralogy and microbiology in predictive ways could aid in modeling biogeochemical cycles in these systems and perhaps lead to a better understanding of global cycles.

In other more accessible systems, the connections between minerals and microbes have been interrogated, and links have been drawn between specific minerals and the microbial communities associated with them (for example Reardon et al., 2004; Ransom et al., 1999). The idea of microbe-mineral associations has also been investigated at hydrothermal vents (Kormas et al., 2006), but the focus has been on comparing the communities from inner, middle, and outer sections of chimney walls, rather than looking primarily at specific minerals as drivers of community composition. At vents, certain mineral precipitates are very common, but their relative abundances vary widely, while others are more rare. If mineral assemblage itself can be shown to be predictive of microbial community, and in turn activity, a vast number and diversity of archived samples can be investigated, and conclusions can be drawn from them about the community they host and the activity of that community.

Hydrothemal vent chimneys are an ideal locale for studying the relationship between mineral assemblages and microbial communities. The vent fields along the Juan de Fuca Ridge host markedly different mineralogies. Most striking, perhaps, is the contrast between Middle Valley and other vent fields. Middle valley sulfides collected in July 2010 consisted of friable, thin-walled, anhydrite-rich chimneys. In comparison, sulfides recovered from Main Endeavour, High Rise, and Mothra vent fields lacked obvious anhydrite deposits, were more silicified, and often consisted of thicker walls, friable interiors, and notable pyrite and marcasite deposits. My research is broadly aimed at better understanding the relationship between mineralogy and microbial community composition and activity, within and among sulfides.

From Mantle to Magma to Gabbros to Basalts to Hydrothermal Vents: How do we put the pieces together?

Mike Perfit

Dept. of Geological Sciences, University of Florida

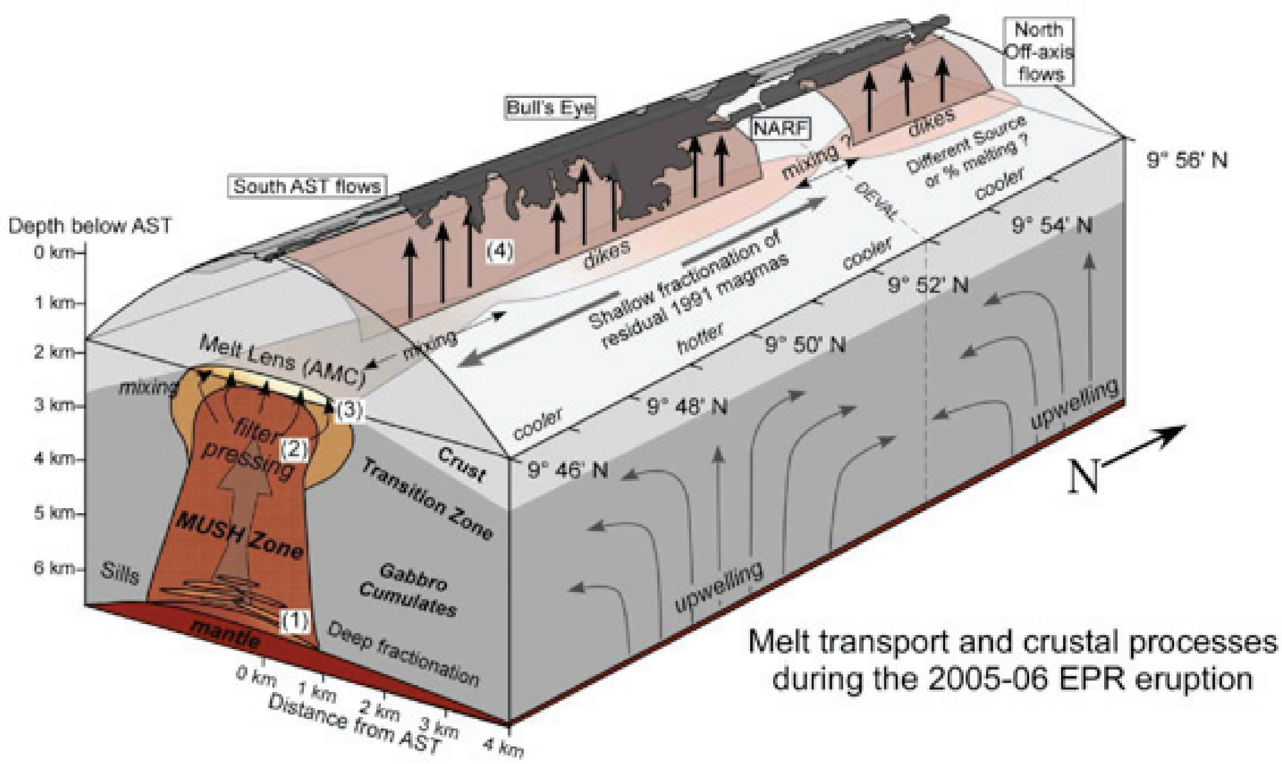
We now have excellent geochemical data from spatially related collections of mid-ocean ridge basalts (MORB) and back-arc basin basalts (BAB) as well as their related differentiates (basaltic andesites, andesites and dacites) from the three Integrated Study Sites (ISS). In addition, significant geophysical, hydrothermal and biological data from these sites are now available. Volcanic units have a much larger range of compositions and flow morphologies than previously thought, hydrothermal cells have been mapped with microseismicity, seismic images show ridge segmentation more clearly and substantiate there are regions of melt away from ridge axes. At the EPR ISS, the first repeat eruption on a MOR has allowed us to evaluate how a ridge erupts and what the effects are on a decadal scale. Detailed ISS studies have provided a rich spatial and temporal view of ridge processes.

Although we have learned much from our detailed observations, the physical and chemical processes associated with mantle melting, transit of melt trough the lithosphere and eruption on the seafloor are incompletely understood. At this point it is imperative for us to focus on synthesizing and integrating our various observations and data sets in order to gain a better understanding of the causal links between observed geological, geochemical, hydrothermal and biological processes associated with MOR and Back Arc crustal accretion. Now is the time for us to relate both the timing and character of ridge volcanic and tectonic events to variations in the ridge crest structure, topography, magmatic plumbing, hydrothermal plume and vent-fluid chemistry, and vent-biological community structure at a variety of segment scales. Each of us has pieces of the ridge puzzle that we have carefully developed but how do we put them together? Are there any critical pieces missing? How can we facilitate the collaboration needed to put all the pieces together to see the “big picture”?

One of the pieces that is missing at the ISS is a depth perspective – we have little to no idea of the structure and composition of the lower crust. Exposures of upper mantle and lower crust along spreading centers has led to new ideas about mantle melting, melt transport, rock-melt interactions and hydrothermal processes at depth - primarily at slow and ultraslow ridges. Additionally, successes in deep drilling of ocean crust away from volcanically and hydrothermally active spreading centers have confirmed the linkages between hydrothermal activity and magmatism, and have extended our view of the magmatic processes in the lower crust and their thermal and chemical effects on the upper crust. Can these observations be used to give us a more complete picture of the ISS sites and visa versa; can ISS data help us to understand regions where the upper crustal variation is poorly known?

At this meeting we need to identify and help facilitate connections between research groups and individuals from different and overlapping disciplines in order for them to more easily collaborate on joint projects where data and ideas can be integrated. Funds should be made available for small groups to meet to begin this process that hopefully will start during this meeting.

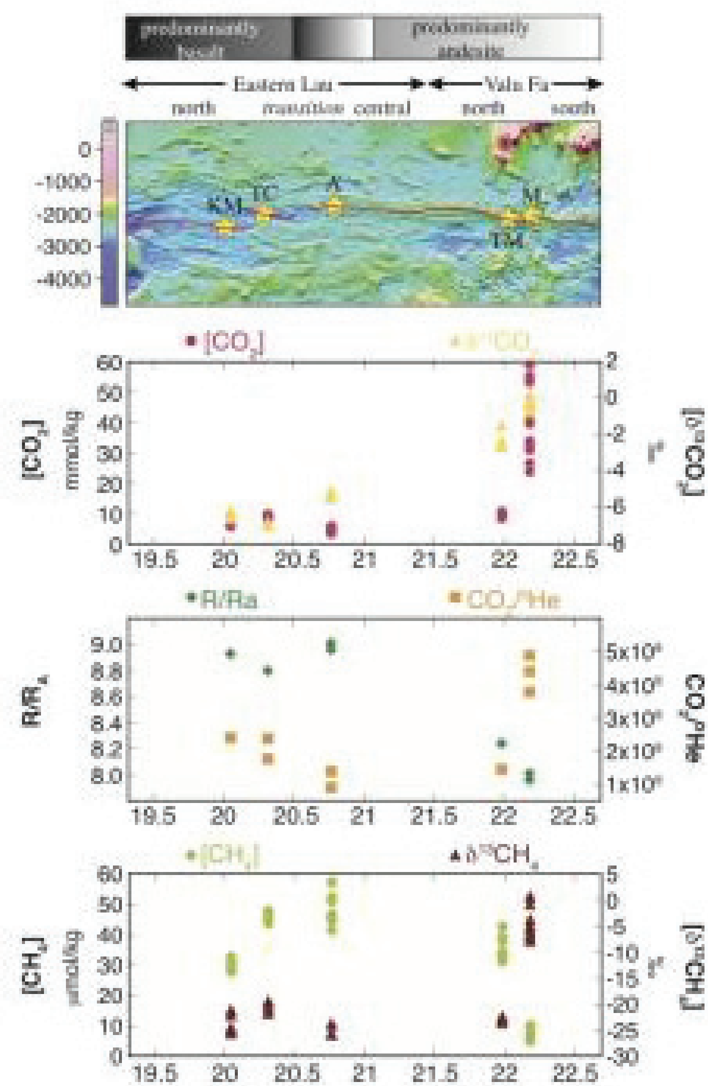
Model of the magmatic plumbing beneath ~9°50’N EPR associated with 2005-06 eruption (from Goss et al. 2010)



Reconciling vent volatile fluid chemistry across Lau Basin with rock geochemistry

Giora Proskurowski
University of Washington

The Eastern Lau Spreading Center (ELSC) is oriented so that the southern sections of the ridge are closer to the Tonga Trench, and thus exhibit increasingly arc-like characteristics north to south. Most prominently, there is an abrupt shoaling of the ridge axis at around 20.5°S latitude (~2700m to the north, ~2200m to the south), a corresponding change in the primary rock type (basalts to the north, andesites to the south), and a much more consistent presence of an axial magma chamber to the south (Jacobs et al., 2007). In addition, the trace element geochemistry of the rocks from the ELSC shows to main groups, with the abrupt geochemical transition again occurring in the 20.5-21°S latitude region (Escrig et al., 2008). One important piece of data that does not perfectly fit with the notion of a rapid transition between MORB-dominated and arc-dominated upper crustal sections is the d13C-CO_2 values from vent fluids. There are six known active hydrothermal sites along the ELSC/ValuFa ridge (from north to south: Kilo Moana, Tow Cam, Tahi Moana--discovered by the Chinese in 2007, ABE, Tui Malila, Mariner, and Vai Lili), where Tahi Moana and Abe occur at ~2200m, just south of the major transition. The carbon-13 isotope ratios of CO_2 sampled form these fluids exhibit an extremely linear trend from a typical basalt-hosted value of -6‰ at Kilo Moana, to a typical arc-influenced value of 0‰ at Mariner. This may suggest that the hydrothermal fluids may be integrating the full upper-crustal section, and that the surface rocks may not be the whole story. Assuming this--that there is a smooth rather than abrupt gradient in melt geochemistry—perhaps there is some chemical threshold at which the physical eruptive expression of melt abruptly changes.



Mantle and magma dynamics along the mid-ocean ridge system: combining ISS-scale with regional-scale perspectives

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Seafloor accretion at mid-ocean ridges is driven by transport of energy (heat) and mass (magma) from the mantle to the crust. Global variability in axial morphology and ridge segmentation reflect the variability in mantle temperature, spreading rate, magma supply, crustal faulting and large-scale plate motion. The R2K Integrated Study Site synthesis of mantle-to-microbe datasets is providing the RIDGE community with a thorough knowledge base for global comparison and investigation of the mid-ocean ridge system. Nonetheless, studies of mantle dynamics and ridge segmentation need to be considered in the context of large-scale (10's to >100's of kms) observations. Thus, there are some inherent limitations to addressing aspects of mantle heterogeneity and flow, ridge segmentation, and regional variability in mantle temperature and melt transport solely from the perspective of individual ISS focus areas. The "Mantle Controls Working Group" should, therefore, also consider existing (and possible future) regional data sets in the integration and synthesis of ISS data. While such regional studies would obviously include current ISS areas, other "analog" localities may provide key information that is currently lacking in the integration and synthesis effort. For example, event response cruises to the Northern Lau Basin broadened the scope of the ISS study for the Eastern Lau Spreading Center. As well, the Juan de Fuca and Gorda Ridges bear on the integration and synthesis of data from the Endeavor ISS. Moreover, many sections of the global MOR system display wide variations in axial morphology and geochemical characteristics over short distances (e.g., Equatorial Atlantic, Southeast Indian Ridge, Pacific-Antarctic Ridge). Regional scale geochemical variations provide important perspectives on mantle flow, mantle temperature and magma supply particularly when key variables, such as spreading rate, are relatively constant (e.g., SEIR; Amsterdam-St. Paul Plateau to the AAD & AAD to the Maquarie Triple Junction).

Most, if not all, R2K sub-disciplines have compelling rationales for expanding the footprint of current ISS areas, as well as for further survey of the mid-ocean ridge system at ocean basin and global scales. The recently released InterRIDGE workshop report, "Long Range Exploration of the Ridge Crests", considers the future of global mid-ocean ridge research (http://www.interridge.org/en/node/6158) beyond the current ISS focus areas, and provides a initial blueprint for addressing the full spectrum of global mid-ocean ridge characteristics and processes.

Bioenergetics in deep-sea hydrothermal systems

Karyn Rogers
University of Missouri

The hydrothermal vents of the deep-sea are in some ways simpler than the shallow marine vents and terrestrial hot springs that are their shallower counterparts. While shallow marine and terrestrial systems are infinitely easier to access, their ecology is complicated by the abundance of photosynthetic organisms and the significant fluxes from ecosystems outside the hydrothermal system itself. Therefore, it might seem that the bioenergetics of chemosynthetic metabolisms would be more tractable in deep-sea environments. However, our ability to calculate in situ bioenergetics is hampered by the difficulties in assessing fluid geochemistry at temperatures and in environments that are relevant to microbial metabolisms. Recent studies of shallow marine hydrothermal vents and terrestrial hot springs shows that in situ measurements of redox sensitive species are essential to properly evaluate the energetics of metabolic reactions at in situ conditions (Shock et al. 2010, Rogers & Amend, 2006; Amend et al., 2003). Much of the early work on deep-sea hydrothermal geochemistry focused on end-member fluids. However, recent advances in electrochemical sensors and voltammetric methods have extended these measurements to include lower temperature and diffuse flow systems. Furthermore, in situ microbial incubators that are situated in chimney walls are helping to elucidate the geochemistry of mixed fluids where microbial communities are thriving. Finally, coordinated geochemical and microbiological studies are beginning to illustrate the relationship between these two datasets.

Despite these advances, it is still not possible to develop a complete picture of in situ bioenergetics in deep-sea vent systems. Geochemical models can be used to estimate fluid compositions for mixing environments (e.g. McCollom & Shock, 1997) and also to predict the potential abundance of otherwise unknown compounds (Schulte & Rogers, 2004; Schulte, 2010), which in turn can guide culturing efforts in hydrothermal systems. Our efforts to link hydrothermal geochemistry and microbial diversity and function can also be aided by laboratory experiments that quantify energy consumption by thermophiles under geochemically distinct and relevant conditions. The geochemical and microbiological datasets acquired through decades of RIDGE research can be combined and hopefully extended to develop a more complete picture or the bioenergetics of microbial metabolisms in deep-sea hydrothermal systems. Furthermore, methods can be designed to use current datasets to guide microbiological experiments in order to further our understanding of bioenergetic requirements of thermophiles at in situ conditions.

Schulte and Rogers. 2004. Geochim. Cosmochim. Acta 68, 1087-1097.
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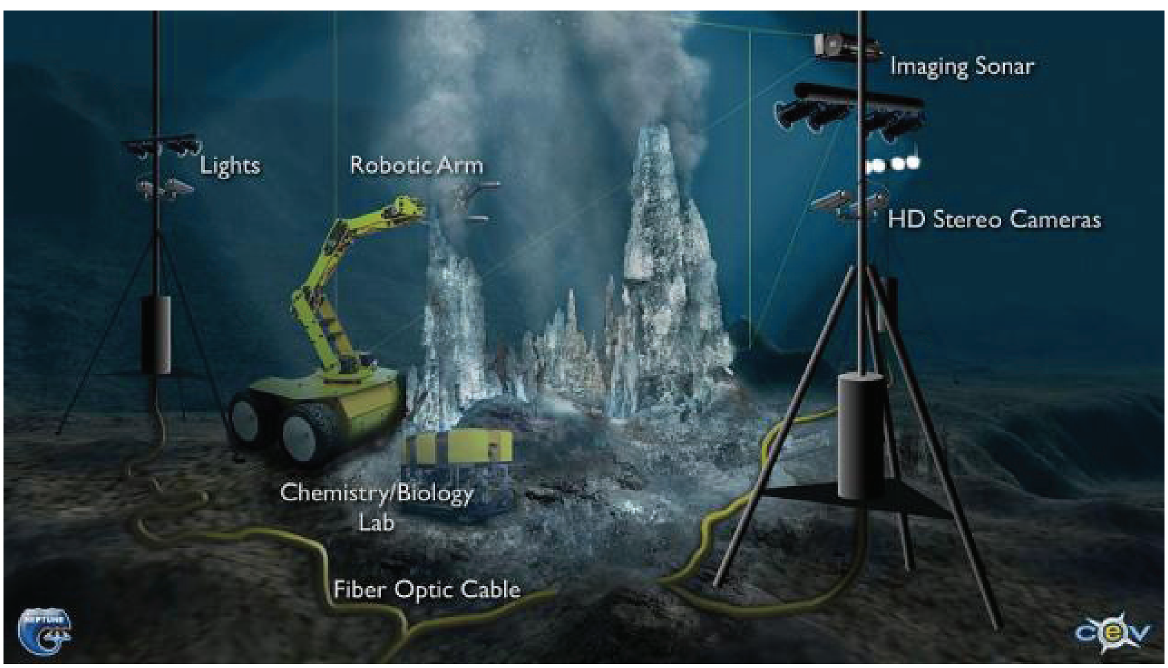
Shock et al. 2010. Geochim. Cosmochim. Acta 74, 4005-4043.
Schulte. 2010. Aq. Geochem. 16, 621-637.
McCollom and Shock. 1997. Geochim. Cosmochim. Acta 61, 4375-4391.

Cabled Observatory Vent Imaging Sonar (COVIS)

Peter Rona
Rutgers University

A key to integration and synthesis of collaborative multidisciplinary oceanographic studies between PIs is collocation of sensors. However, collocation of sensors when performing our studies on ocean ridges is one of the biggest challenges that we face. For example, an apparent schism exists between those who study the chemistry and physics of high-temperature hydrothermal black smoker vents and the biological community that studies vent ecosystems in lower-temperature diffuse flow.

Our group from Rutgers and the Applied Physics Lab-University of Washington, has developed a sonar system and the methods to acoustically image and quantify the flow from both black smoker vents and diffuse flow. Our sonar system has evolved through operation from Human Occupied Vehicles (HOVs), to Remotely Operated Vehicles (ROVs), to our present adaptation of the sonar to connect to the NEPTUNE Canada Regional Cabled Observatory (RCO). We are in transition between two modes of operation: (1) the ROV mode of acoustic imaging that enabled us to collect and quantify acoustic imagery of plume and diffuse flow (additional publications in preparation) but falls short in terms of collocation of sensors; and (2) the Regional Cabled Observatory (RCO) mode of operation with NEPTUNE Canada that is enabling us to collocate our remote acoustic imagery with in situ instrumentation of other PIs. This collocation phase will begin this fall 2010 when we are scheduled to connect our sonar to the NEPTUNE Canada RCO in collaboration other PIs at a vent cluster in the Main Endeavour Field (Grotto vent). We will then begin to transmit to the community through NEPTUNE Canada a data stream of acoustic images of smokers and eventually diffuse flow for scientific synthesis as part of the NSF Ocean Observatories Initiative (OOI).



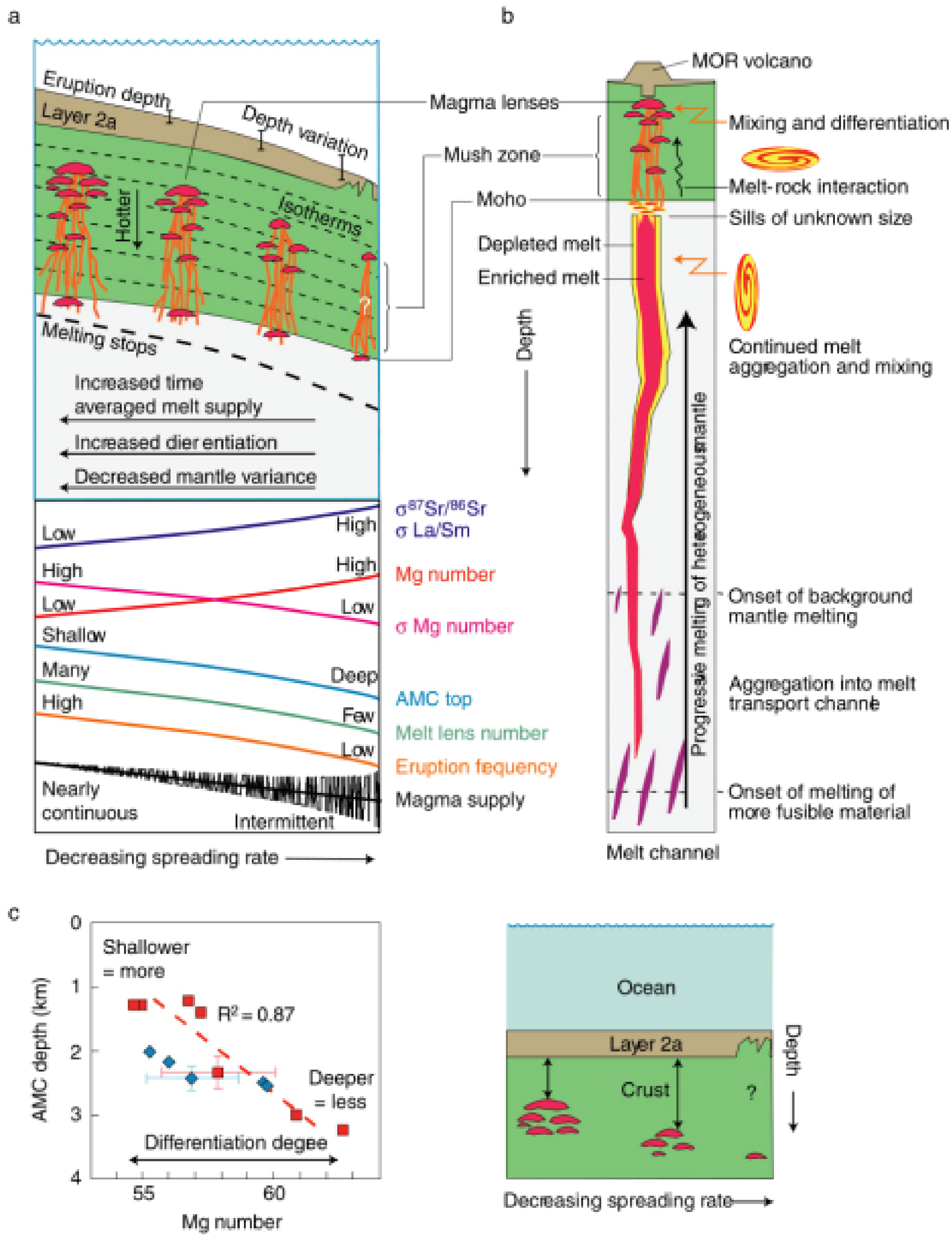
The causes and effects of melt supply variations on ridge volcanism and tectonism

Ken Rubin
Dept. of Geology and Geophysics, University of Hawaii

We take it for granted that mantle melt is supplied to the crust to feed mid ocean ridge volcanism. Most ridge geologists will also agree that this magma supply probably varies somewhat at any given spot on the ridge. There are examples in the literature where magma supply fluctuations have been invoked to explain local variations in ridge morphology, volcanism, tectonic history, and the style and extent of hydrothermal activity in space and time along ridges. Ridge morphology and depth indicate that spatial variations in magma supply almost certainly play a role in ridge processes in the EPR and Lau Integrated Study Sites (ISSes), and temporal variations likely apply to all three ISS - but we don't yet know by how much or at what frequency.

Three critical questions that remain to be answered relate to the causes, frequency and magnitudes of magma supply fluctuations, which feed directly into the central R2K question of what is the flux of heat and material from the mantle to the oceanic crust and the oceans themselves. Ultimately the answers will come from combined efforts of many people working at different spatial and temporal scales in many more geographical locales than the current three R2K ISSes. Some of these studies have already been conducted and their results only need to be synthesized and integrated to provide a fuller few of the overarching controls on melt supply to ridges. By putting together the multiple types of data that are ready or nearly ready to be integrated into a better understanding of the causes and effects of melt supply fluctuations at ridges, we can identify new observations, data analysis methods, and/or modeling approaches that are required for future efforts on this topic. Examples of existing observations include detailed geologic mapping of tectonic and volcanic features at sites on the EPR, JdF and MAR, among other places, and chemical analyses of associated lavas: these provide information about the sizes and durations of crustal accretion, rifting and faulting events. Compositional attributes of magmas that vary at local and global scales in response to long term, time integrated estimates of melt supply also provide clues about underlying processes. And studies of the size and distribution of crustal magma bodies, and their relationships to ridge segmentation and magma compositional variations along axis, are also key. Some of these types of observations and their implications for melt supply, which may not be widely known to the R2K community, are summarized in two recent papers that look at these issues from the crust (Rubin and Sinton, EPSL, 2007, vol. 260) and mantle (Rubin et al., Nature Geosciences, 2009, vol. 2) perspectives, respectively. Plus, the author has relatively new non-Ridge 2000 funding from NSF-OCE to study local and regional scale melt supply fluctuations on ridges in the eastern Pacific Ocean (JdF, EPR and GSC), which I can provide details of at the meeting.

Clearly, a full understanding of the causes and effects of melt supply variations on ridge volcanism and tectonism requires a multiscale and multidisciplinary approach. One of my goals for the meeting is to help bring these global and local scale observations (made both at and outside of the ISSes) to the attention of others, and to learn how they relate to other data sets, observations, and hypotheses from participants of the crust and mantle Working Groups, to address the extents of local magma supply variations at ridges, their root causes in the mantle, and their effects on crustal processes.



KH Rubin, Sinton, J.M., Maclennan, J., Hellebrand, E. (2009)Magmatic filtering of mantle compositions at mid-ocean ridge volcanoes, *Nature Geoscience*, 2, 321-328.

Figure caption: Cartoon MOR cross sections summarizing the types and scales of mantle compositions, the magmatic processes that sample them, and the resulting effects on erupted MORB compositions (from Rubin et al. 2009 and references therein). The spatial scale of mantle compositions, the manner in which melts are produced, transported and pooled in the mantle, and crustal magmatic processes and thermal conditions all affect how mantle compositions are sampled by MOR magmatism. We don't know how often these processes vary or at what length scale, or the attendant effects on MOR volcanism.

Time and length scales of volcanic unrest signatures at submarine volcanoes

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1. *University of Hawaii*
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3. *NOAA-PMEL*

Volcanic eruptions at mid-ocean ridges and other submarine volcanoes are fundamental "events" that impact nearly every aspect of the biogeochemical system, including: resurfacing the seabed, partially draining magma chambers, inducing seismicity and slip on faults, initiating new faults and fissures, impacting hydrothermal circulation patterns and conditions of water-rock exchange in the crust, altering seafloor morphology, perturbing both vent and non-vent ecology, and causing the exhalation of large quantities of fluids and crust-dwelling microbes into the overlying oceans.

The timing, frequency and spatial extent of eruptions are important for establishing a "time zero" point to assess the recovery of the volcanic system and/or if there were multiple "reset" points closely spaced in time. These parameters are also crucial for an understanding of the longer term evolution of the volcanic system. An important question that has generally not been quantitatively addressed is the duration and spatial extent of perturbations caused by eruptions within the crust, on the sea floor, and in the overlying water column, or their overarching controls. Such information – time since the last eruption or intrusion and the size and duration of an event – is essential for interpreting biological, hydrothermal and geological observations at submarine volcanoes in the years and decades following and/or preceding magmatic events.

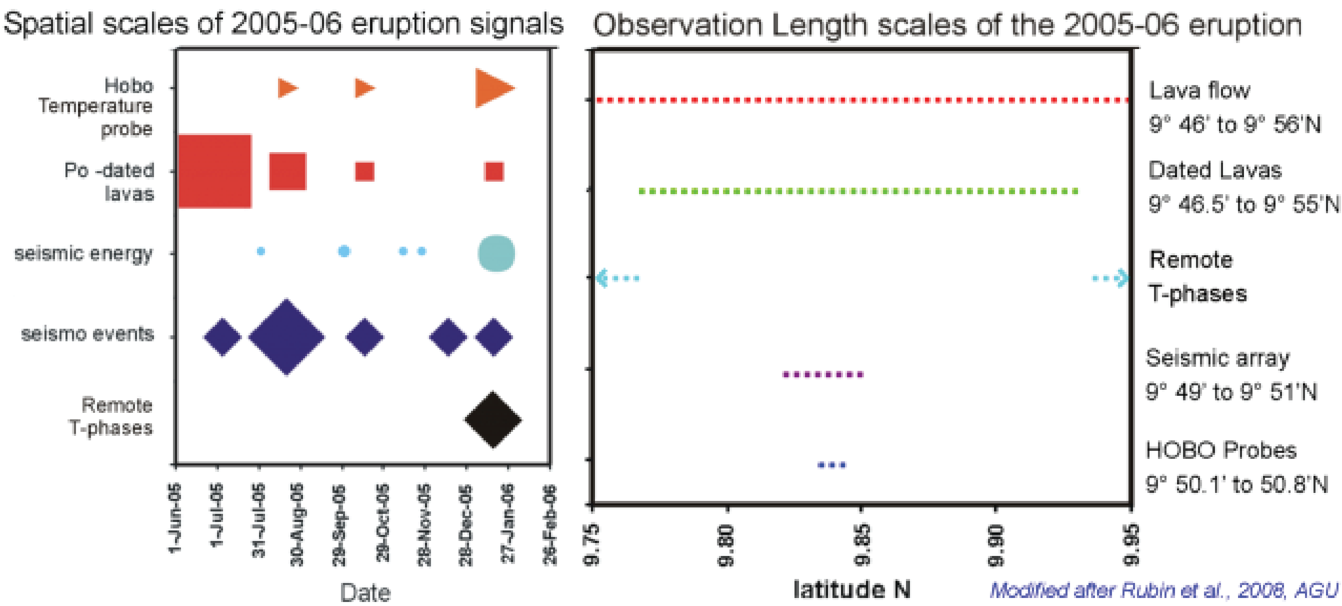
A great deal of information from observations at a dozen or so sites in the past 25 years can be synthesized to develop a greater understanding of the relevant spatial and temporal scales of eruption–related phenomena. For instance, eruptions at 9° 50'N EPR, with fissure lengths of ~10-20 km, impacted hydrothermal sites tens of km outside the zone of lava emplacement. Hydrothermal fluids at chimneys within the eruption zone showed a continual decay of compositional effects for nearly a decade after the 1991-92 eruption. These fluids then began to reverse some of these compositional variations a few years prior to the next eruption (in 2005-06). Both of these EPR eruptions produced lava flows over a period of six months or more. The 1998 Axial Seamount eruption was shorter in duration, and the number and intensity of pre-existing hydrothermal vents increased for a time after the eruption, after which it returned more or less to pre-eruption conditions. We don't know the duration of the ca 1986 N. Cleft eruption and a slightly older related sheet flow on the Juan de Fuca Ridge (JdF), but there was limited focused hydrothermal flow up to 2 years after the eruption. Other eruptions, such as the 1993 Coaxial eruption on the Juan de Fuca Ridge and the 1996 N. Gorda Ridge eruption were short lived events that did not spawn active, focused hydrothermal flow, and had only short-lived biological effects in the immediate vicinity of the eruption.

It is useful to ask what caused the aforementioned differences? Are they effects of different volumes of erupted magma, conditions of lava effusion, magma storage depths in the crust, and/or crustal fracture regimes, perhaps influenced by eruption locations nearer to segment centers or segment ends?

Another key to the time and length scales of eruptions comes from monitoring data collected during and between sea floor eruptions. In situ seismic data, remotely detected T-phase seismicity, hydrothermal fluid exit temperatures, high-resolution lava eruption ages, long-term ground deformation monitoring (inflation/deflation), and depth changes (which can constrain erupted volumes) are available for one or more eruption, and tell a complex story of the event(s) that occurred. No two records tell exactly the same story, and in some cases, are contradictory (such as eruptions at Loihi in 1996 and 9° 50'N EPR in 2005-06 that produced little if any obvious change in regional seismicity). Examples of some of these types of differences are shown graphically in the attached figure for the 2005-06 EPR ISS eruption.

The first step towards understanding the temporal and spatial scales of eruptions is to compile all the relevant data collected at and near eruption sites by a long list of individuals operating under the auspices of RIDGE

Event Detection and Response, R2K Time Critical Studies, NOAA-Vents program, and independent responses. Next would be to look for similarities and differences between the catalog of known events, and to compile eruption metadata from the principals in those studies, some of which is not well documented in the literature. These data can then be compared to more intensively monitored volcanoes in terrestrial environments and finally the data can be integrated into one or more papers. It is anticipated that the "geologically" focused effort described here will dovetail with companion efforts aimed at understanding the biological evolution of the sea floor at active volcanic sites



Size, Timing and Length scales of Submarine Eruption signatures

Figure caption: Magnitudes of signals with time and spatial scales of observational data from the EPR 2005-06 eruptions. The sizes of the symbols in the left panel are proportional to the relative magnitude of each parameter at different points in time. The plot illustrates that different aspects of the system responded differently to, and thus recorded, different aspects of the eruption. Figure from Rubin et al. in prep, modified from Rubin, KH, Tolstoy, M, Fornari, D J, Dziak, R P, Soule, S A, Waldhauser, F, Von Damm, K L (2008) Integrating Radiometric, Geophysical and Thermal Signals of Volcanic Unrest and Eruption in 2005-06 at 9 deg 50'N EPR, Eos Trans. AGU, 89, Fall Meet. Suppl., Abstract # B23F-07

A Working Group Approach to Integration and Synthesis of Mid-Ocean Ridge Studies

Ken Rubin[1], Dan Fornari[2]

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2. *Woods Hole Oceanographic Institution*

Introduction and Background

The overarching goal of the Ridge 2000 program is to answer key questions pertaining to fundamental processes that control biological, chemical and geological phenomena at oceanic spreading centers using observational, experimental and modeling data derived from the past few decades of research on mid-ocean ridges. The program has completed many successful field campaigns and shore-based research projects, resulting in the publication of a large volume of scientific papers spanning many subjects. The task the program now faces is how to synthesize the accumulated knowledge from the past ~8 years of field and laboratory data, and decades of allied research, into widely accessible published products. This synthesis is expected to yield new insights into oceanic spreading center processes, impact multiple related research fields, and pave the way for new scientific directions that will extend our knowledge of fundamental earth-ocean processes.

The work of Ridge 2000 (R2K) is multi-disciplinary. Answering some of the broader research questions posed in the R2K science plan requires a collaborative, cross-disciplinary approach that has proved difficult thus far to initiate on a community wide scale. One difficulty has been the delay of key experiments at some sites, with the result being that key data sets have only recently been collected and published, or are in the final stages of publication. Nevertheless, there is a general consensus that R2K has contributed substantively to both the ocean sciences in general and in a focused way to multidisciplinary studies at ridges, both through the scale of the effort and through the development of new technologies required to study seafloor processes. However, the successful completion of the synthesis of R2K scientific results both within and across the key study areas (aka Integrated Study Sites) is required to demonstrate that R2K has fully reached it stated program goals. We expect that many in the program will see the results of this effort as both a very satisfying culmination to decades of MOR research and a roadmap to future questions and research on the general topic.

The Working Group Approach

This white paper describes how a team-work approach to the synthesis of R2K scientific results, using topical/thematic working groups with foci that address a subset of the overall program goals, can be used to advance integration and synthesis goals of the R2K program. This method has proved successful in multiple other research venues.

The idea in a nutshell is to use topical and ISS focused working groups to formulate ideas, stimulate discussion, and synthesize results on program-relevant topics into high profile publications. This effort uses a systems approach, focusing the groups toward different ridge processes and/or structural elements of ridge environments. It differs from the largely geographic (ISS and cross-ISS) focus R2K has used for the past 3 years of community meetings.

Working groups will be formed in conjunction with a research community-wide meeting with group topics loosely defined by the meeting organizers. Groups will work together before, during, and following the meeting to choose topics and datasets within their focus area that are ready for this synthesis effort, work toward integrating and synthesizing knowledge on them, and write and publish synthesis papers. Large groups may choose to work as several subgroups if this best meets their needs. In other research communities, the most successful implementations of the working group approach suggest that the R2K groups will be maximally productive if they operate over a one to two year period, and if members of multiple disciplines are committed to communicate, learn from each other, and develop a shared-vision for their objectives and published products. Thus, the products of the groups will be developed over time, with the hope that additional collaborations are born from this process and that new ideas spring from the synthesis effort. While we hope that some of the ideas and papers developed at the community meeting can be published in the following year, we fully realize that in some cases this process may take longer.

Interactions within each working group:
Each group will likely comprise approximately 10 participants of different backgrounds, perspectives and seniority levels. Groups should therefore have a high degree of flexibility in terms of how they interact and schedule their interactions, and how they divide up tasks to individual members. But, group interactions should nevertheless be guided by functional and ethical protocols established by the architects of this effort before the groups meet. Groups should have multiple tools and venues for interaction at their disposal, including telecommunications, virtual meeting, on-line forums and in-person meeting options.

Working Group Leaders:
To be most effective, each group should have several leaders who are generally knowledgeable about the topic, open-minded, and willing to commit to the effort. These leaders will jumpstart discussions, facilitate the integration and synthesis process-before, during and after the meeting, and referee the interactions within the group. They need not be the leaders of paper writing efforts that arise from the group, but certainly can choose that role if they wish.

Integration and Synthesis Leaders:
The overall effort described here needs a few higher level leaders that will devise the structure and operating protocols of the working groups and the community meeting, interact with group leaders, mediate sticking points that might arise within groups, and generally steer the overall process.

The Community Meeting:
The role of the community meeting is to bring all the groups together face-to-face after they have had a chance to begin interactions, to give them the opportunity to have focused, multi-day discussions on the work at hand, set schedules for producing their group products, and to learn about the work of other groups, including topics they are addressing and successful collaboration modes. The community meeting is a means to an end, rather than a specific, fixed time frame to accomplish the synthesis effort. The key point is that the meeting can serve as an impetus for the community to embark on the path that will lead to fully capitalizing on R2K research to date, by synthesizing and integrating information to achieve a more complete knowledge of MOR processes.

Community Commitment to Achieving R2K Program Goals
To be successful, large-scale scientific research programs such as R2K require vision, innovation in conceptualization and execution of its studies, community participation at all levels, and funding agency support over the term of the program. In practice the 'net-worth' of a large-scale research program is measured by its productivity, both in terms of scientific results and in terms of impacts on the field(s) of study. R2K has in many ways been the vanguard of 'multidisciplinary' ocean-earth studies and has demonstrated how researchers with a broad array of research tools, methods and practices can work together on shared research goals. Researchers involved in the program have a strong desire to understand the 'interconnectedness' of MOR phenomena as epitomized by the 'Mantle to Microbe' iconic statement that ushered in R2K nearly 10 years ago. The process will be challenging, but we believe the community is ready for an organized effort like the one described here

U-series constraints on magma supply, mantle source and melt migration along mid-ocean ridge spreading centers

Chris J. Russo and Ken Rubin

SOEST- Department of Geology and Geophysics, University of Hawaii

U-series disequilibrium in volcanic rocks provides unique insight into magmatic processes and their timescales. There is a significant literature of applications to mid-ocean ridge basalts that can be applied to the Ridge 2000 Integration and Synthesis goals. For instance, disequilibrium between relatively short-lived 210Pb (t1/2=22.3 yrs.) and 226Ra (t1/2=1600 yrs.) in MORB indicate rapid transport of melt from the mantle to the crust over timescales of 10's of years and equally short crustal magma chamber residence times (Rubin et al., Nature, 2005, vol. 437). Longer-lived 230Th (t1/2=75,000 yrs.) activities and (226Ra/230Th) and (230Th/238U) are more sensitive to melting rate and source lithology in MORB (e.g., Sims et al., GCA, 2002, vol. 77). Disequilibrium amongst these longer-lived nuclides is sensitive to both elemental fractionation during melting and the melting rate (%melt/km upwelled), making it a unique and powerful tool for understanding mantle upwelling conditions and identifying the presence of even small amounts (≤5%) of enriched lithologies in mantle beneath spreading ridges (because the high modal abundance of clinopyroxene in most enriched mantle lithologies enhances their fusibility and thus melting rate). As a result, high melt productivities of such lithologies produce magmas with low 230Th and 226Ra excesses and distinct trace element concentrations while only contributing a small amount to the total melt volume delivered to the ridge axis (e.g., as demonstrated along the Southeast Indian Ridge; see attached figure from Russo et al., EPSL, 2009, vol. 278).

U-series characteristics in MORB from both the 1991-92 and 2005-06 eruptions within the EPR ISS at 9°50'N has provided a unique opportunity to explore decadal variations in crustal level magmatic processes at, and melt supply to, this well characterized ridge segment. Collectively, similar measured values of (230Th/232Th) and (238U/232Th) in lavas from both eruptions, higher measured Th, U, Ra, Pb, and Ba concentrations in 2005-06 Bullseye lavas, and smaller 210Pb-226Ra disequilibria in 2005-06 lavas compared to those erupted in 1991-92 are consistent with decay and differentiation occurring in a closed magma system over a 16 to 60 year time period. Additionally, 2005-06 lavas extend to even higher incompatible element abundances at the northern and southern extremes of the eruption (locations that were not sampled or known to have experienced an eruption in 1991-92). Collectively these observations are consistent with a 2005-06 eruption sequence supplied by either a chemically zoned magma body or a series of disconnected magma bodies that were transported and evolved over short (i.e. decadal) timescales (see also A. R. Goss, M. R. Perfit, W. I. Ridley, K. H. Rubin, G. D. Kamenov, S. A. Soule, A. Fundis, and D. J. Fornari, Geochem. Geophys. Geosyst., 11, Q05T09, doi:10.1029/2009GC002977, 2010).

It is our desire to integrate these observations with other datasets that describe hydrothermal variability, mantle source, magma temperature and melt distribution in an effort to produce a holistic view of the role magma plays in terms of supplying mass and heat to the crust of the ridge system within the EPR ISS. An integrated view of this sort is crucial for the advancement of models describing the thermal evolution of the upper mantle and crust within this ISS and elsewhere along the global ridge system and represents one tangible product of a focused synthesis effort facilitated by this workshop.

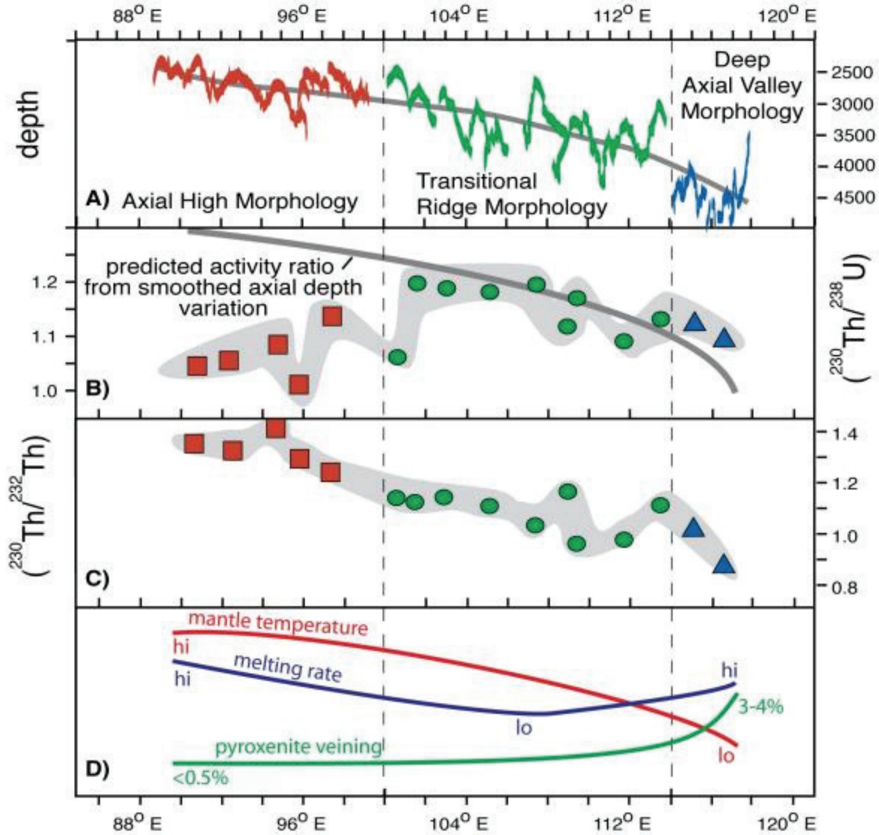


Figure Caption: Along-axis variation in a) ridge depth/axial morphology, b) 230Th-excess, c) (230Th/232Th) and d) schematic representation of the competing effects mantle temperature and mantle lithology have on melting rate along the Southeast Indian Ridge from 88° to 118° E (modified from Figure 5 of Russo et al., EPSL, 2009, vol. 278).

Length scales of mantle heterogeneities and mantle control on ridge segmentation?

Vincent Salters
NHMFL/FSU

Isotope systematics of basalts provide information on the distribution of different mantle components as well as the length scale of mantle heterogeneity. However, many data points are required to obtain a picture with a useful resolution. Here we present new hafnium isotope data on over four hundred samples. This study makes a significant step determination of both location of mantle components and order of mixing. Our new data for mid-ocean ridge basalts (MORB) shows that on a "local" scale hafnium and neodymium isotopes are correlated, and on a global scale they form parallel arrays in this isotope space (see Fig.1). These data are consistent with the asthenosphere consisting of domains with dimensions of several hundred to a thousand kilometers at which the fractions of the recycled materials in the mantle components are constant. Both oceanic crust and mantle residual after extraction of MORB are recognized as recycled components and significant amounts of these components reside in the MORB-source; i.e. the convecting mantle. The "local", smaller, scale variation in neodymium and hafnium isotopic compositions results from the addition of a mantle component with less radiogenic neodymium and hafnium isotopic composition. Beyond this length scale the domains differ in the amount of recycled components in the asthenospheric mantle.

Both MORB and OIB show characteristics that indicate that the Pacific Ocean mantle is distinct from the Indian or Atlantic Ocean and is on average less depleted. Global comparisons of ridge basalts should be cognizant of these large-scale differences.

On a smaller scale, a study along the EPR between 60N and 180N shows that the ridge segmentation coincides with chemical discontinuities. Along this section of the EPR there are four transform fault zones and four overlapping spreading centers. Across each discontinuity the source components change (Fig. 2). These systematics indicate that there is no transfer of magma across the discontinuities as the chemical gradients are largest across the discontinuities. A detailed study of the Siqueiros Fracture Zone, which has active volcanism in the fracture zone, confirms this observation. The trace element and isotopic variations of the fracture zone basalts and its adjacent segments shows that the fracture zone draws melts that can be sourced from either side of the fracture zone, but the basalts from the adjacent segments do not have a common source.

It is therefore important that the each location is placed in its regional context. Since segmentation and source composition are related, comparison of ridge segments, especially across ocean basins should consider regional variations as well as differences in source compositions. Since the variations in source composition can be related to the fractions of enriched and depleted components in the source, we can use the isotopic differences to estimate melt behavior. Although differences in spreading rate have an important influence on the morphology of the ridge and the range of variations in the basalts chemistry, the fact that segmentation can be related to mantle source indicates that source composition also has a significant influence. For example, the existence of an axial magma chamber is dependent on the magma supply rate. Magma supply is dependent on the location of the mantle solidus which, on average, will be different for the Atlantic Ocean basin which has a higher fraction of a depleted component than for the Pacific Ocean basin.

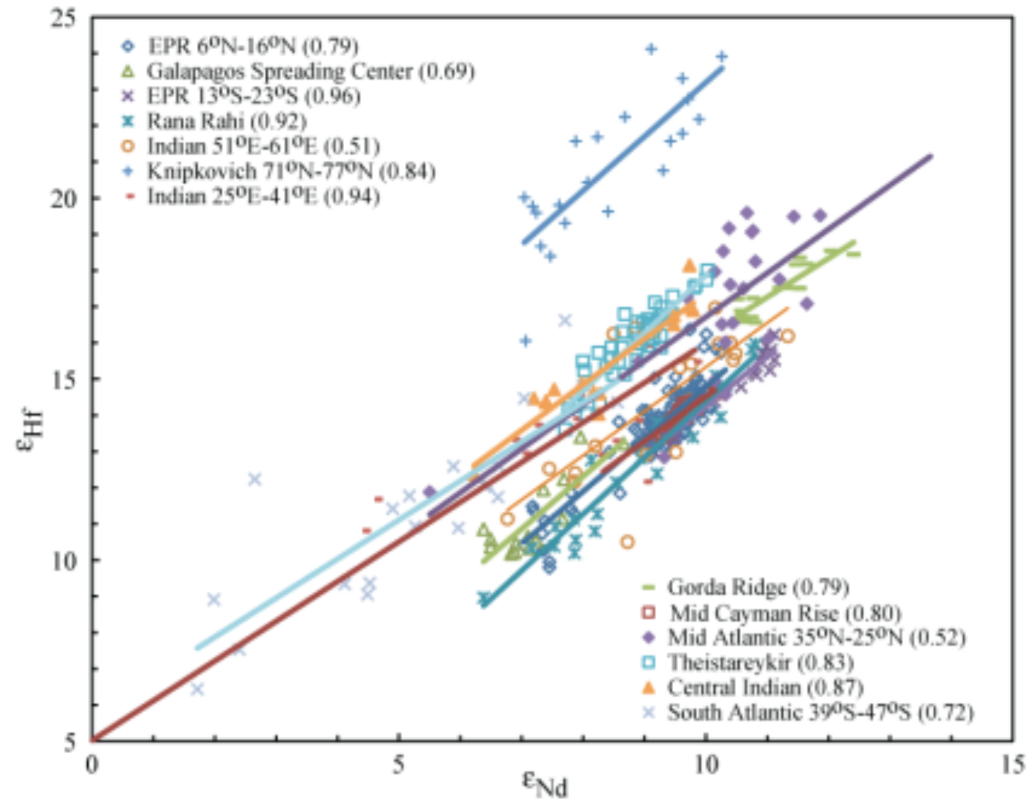


Figure 1: Hf, Nd isotope variations in MORB and the Rana Rahi seamount province. Correlation coefficient for the different ridge segment are indicated as R^2 values in parentheses.

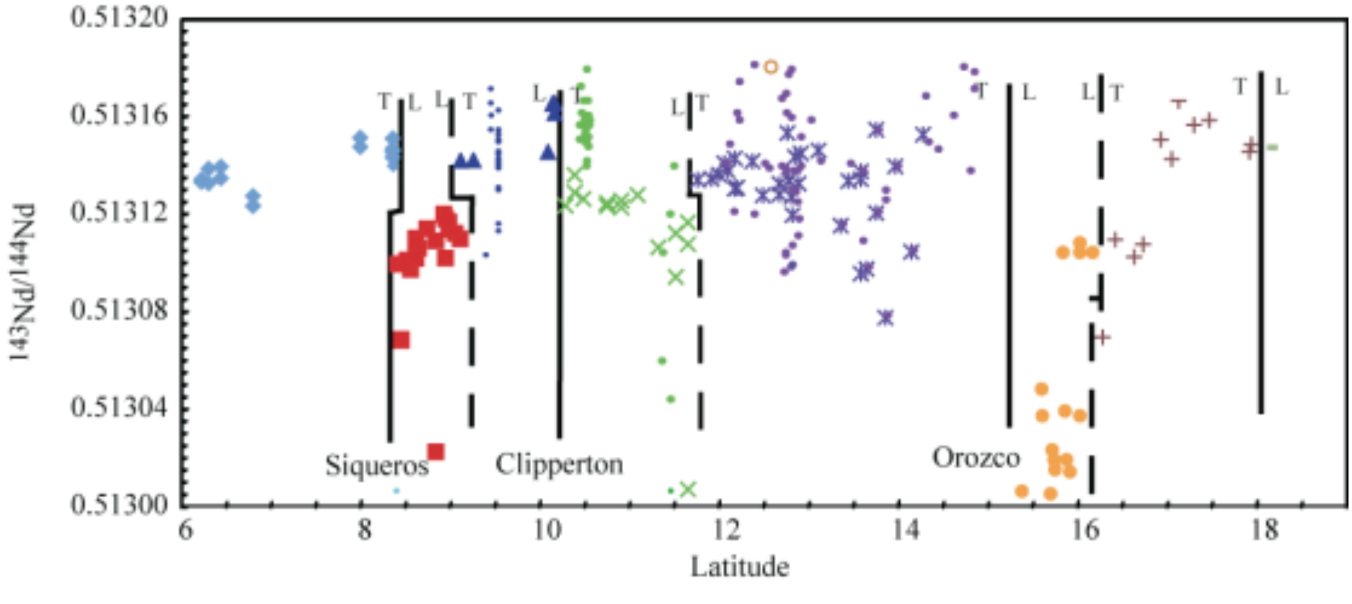


Figure 2. Solid lines are transform faults, dashed lines are overlapping spreading centers. At every ridge discontinuity there is an offset in Nd isotopic composition. Large symbols are unpublished data from FSU.

Mid-ocean ridge biogeochemistry and the search for extraterrestrial life

Mitchell Schulte
University of Missouri

Studies of Earth's deep biosphere over the past few decades have shown that remarkable varieties of environments previously thought to be uninhabitable actually harbor significant quantities and a great diversity of microbial life. It has become apparent that many of the microorganisms living below the Earth's surface rely on geochemical reactions rather than photosynthesis as metabolic energy sources. Because of similarities in geochemical processes that are likely occurring, there are other examples of celestial bodies in our solar system that may also harbor subsurface biospheres, most notably Mars and the jovian moon, Europa. We can use lessons learned through investigations of Earth's deep biosphere to assess the possibility that life may exist below the surface of these worlds.

One of the major tools at our disposal for making these comparisons is geochemical modeling; such models are used to investigate the biogeochemical reactions that are likely to yield energy as water reacts with rocks and as fluids far from equilibrium with one another (e.g. vent fluid and seawater) mix together. In order to construct these models, we take advantage of the vast database available of the composition of host rocks and vent fluids from a variety of hydrothermal systems from the more silicic and acidic fluids found at Lau to the very reducing, high pH environments of Lost City. As such, these models represent one of the best methods for integrating and synthesizing the efforts of mid-ocean ridge researchers and expanding the impact of the Ridge program into the field of astrobiology.

During this meeting, I hope to discuss some of what we know about Earth's deep biosphere in the context of what it may tell us about the nature of life in similar environments outside of Earth. As plans are made for missions to search for deep biospheres on other worlds, we also explore what may be the most appropriate analogs here on Earth and how the methods being developed to study Earth's deep biosphere may aid in our search.

Temporal Evolution of Vent Fluid Chemistry at the Lau ISS

Jeff Seewald, Geoff Wheat

1. Woods Hole Oceanographic Institution

2. University of Alaska Fairbanks

One fundamental aspect of the R2K program is to elucidate causes and effects of temporal variability during the convective circulation of seawater-derived hydrothermal fluids at oceanic spreading centers. Because the abundance of individual chemical species in hydrothermal fluids are influenced to different extents by subsurface processes, temporal variations represent a powerful tool to constrain the influence of important variables such as temperature, pressure, water/rock ratio, phase separation, injection of magmatic volatiles, and the rates and types of subsurface microbial respiration. Temporal variability in fluid flux and composition also has direct implications for physiological diversity and community structure within vent ecosystems. Accordingly, monitoring the temporal evolution of hydrothermal fluid chemistry has been a major research focus for ISSs located at 9-11°N on the East Pacific Rise and the Endeavour Segment of the Juan de Fuca Ridge. ISS related field work at Lau Basin, however, is relatively recent and previous studies of hydrothermal activity are limited, resulting in the near absence of time-series datasets for hydrothermal activity in back-arc environments. The few available observations suggest that hydrothermal activity may evolve rapidly, although it is presently unclear whether existing models for the temporal evolution of mid-ocean ridge hot-springs (e.g., Butterfield et al., 1997) apply to back-arc environments.

Initial expeditions characterized six sites of hydrothermal venting on the ELSC, showing a range of crustal, fluid, and biological characteristics. Unlike the basalt-hosted hydrothermal systems to the north, the southernmost felsic systems (Mariner and Vai Lili) have high concentrations of magmatic gases that influence fluid composition, depositional structures, and biological communities. Owing to the recent initiation of field work at the Lau ISS, time series data for hydrothermal activity in this region is extremely limited. Preliminary data indicate substantial changes in fluid composition at Vai Lili over a 16-year span during which vent fluid temperature decreased from 334°C to 120°C in 2005. These results, sparse data from 2006, and shipboard pH and temperature data from 30 samples collected in 2009 suggest that the temporal evolution of hydrothermal systems influenced by degassing of felsic magmas may be relatively rapid and follow a path that is not analogous to mid-ocean-ridge hot-springs.

We are currently working to fill this gap in our knowledge by analyzing vent fluids collected in 2009 from 30 discrete isobaric, gas-tight samplers and 7 OsmoSamplers (continuous fluid samplers). These data allow us to gauge the time scales over which back-arc hydrothermal systems evolve and the role that magmatic volatiles have in the evolution of hydrothermal systems and will guide a new temporal and/or spatial conceptual model for an individual vent site or for the entire ELSC. New data available for the Portland meeting will help inform discussions that address the composition and evolution of vent ecosystems, temporal variability in the flux of heat and mass during hydrothermal activity in back-arc settings, magmatic evolution, and the formation of seafloor metal sulfide deposits.

In-Situ Chemical Sensors: Their Development, Testing and Future Directions for RIDGE Science

William Seyfried
University of Minnesota

It has become increasingly clear that the evolution of hydrothermal systems at mid-ocean ridges is inherently dynamic where chemical, physical and biologic processes can change dramatically in space and time. As a consequence of this, efforts have proceeded with a range of initiatives to develop and deploy in-situ instrumentation that is capable of measurement and monitoring of dissolved chemicals and biologically active compounds. Instrumentation of this sort is an essential component of any plan involving development of cabled observatories where power will be available for long-term measurements and data communication from sites on the seafloor to facilities throughout the world. If such observatories are to fulfill their intended potential, however, not only must continued sensor development be a priority, but the new sensors must be smaller, and include supporting instrumentation that allows for programmed calibration, such that the effects of signal drift can be accounted for and quality assurance verified.

Past Accomplishments

Investigators at the University of Minnesota have long been concerned with redox and pH controls on the chemistry of hydrothermal vent fluids at mid-ocean ridges [Ding and Seyfried, 2007; Ding, et al., 2005; Ding, et al., 2006; Seyfried, et al., 2010]. Indeed, the first in-situ measurements of pH and dissolved H2 and H2S in high temperature vent fluids were made at the Main Endeavour Field, Juan de Fuca Ridge in 2005 using solid-state sensors constructed of gold sensing elements and corrosion resistant ceramic materials. Subsequently, analogous measurements have been successfully performed at the EPR 9-10°N (2007-2008), and also at Rainbow vent sites (36°N) on the Mid-Atlantic Ridge (2008) [Seyfried, et al., 2010]. Simultaneous in-situ measurements of these species have placed previously unavailable constraints on the compositional evolution of the subseafloor reaction zones from which the fluids are derived. Recent advances have also been made with chemical monitoring instrumentation. For example, in 2008 an auto-calibrating pH monitoring system was deployed for the first time at EPR 9°N in diffuse flow vent fluids. This system included process control hardware and software that permitted intermittent measurement of pH buffer fluids at intervals of approximately six hours, providing effective calibration for the in-situ pH data of the diffuse flow vent fluids that were obtained simultaneously.

Future Directions

We believe it is imperative that in the future efforts be focused on the development of a new generation of sensors that take full advantage of recent advances in micromachining approaches to decrease sensor size, while increasing sensitivity, especially for low temperature applications. The small sensor size will not only expand the range of seafloor applications, but will also mean more frequent calibration cycles for a given volume of standard solution, and thus, permits longer operation. Experimental and field programs should be conducted in parallel such that key cause and effect variables can be isolated and simulated in the lab. Field deployment should occur only after successful performance in the lab at simulated vent conditions. Finally, the ocean science community must be diligent to do all it can to entrain scientists and especially engineers with backgrounds in material science, micromachine-sensor design, and process control systems if the challenges of chemical sensor measurement and monitoring at deep sea vents are to be successfully overcome. Although we emphasize pH and redox sensors, the interdisciplinary approach we advocate can be used as a model for instrumentation development involving an even broader range of chemical sensor systems.

Reaction Progress and Microbial Communities

Everett Shock
Arizona State University

Reaction progress is a way to quantify the extent to which a system has changed from an initial state far from equilibrium to the corresponding equilibrium state. It is an explicit evaluation of the state of disequilibrium in a system. Chemotrophic microbes depend on disequilibria for energy, and only populate systems that have not yet reached equilibrium. The extent of progress of an energy- or nutrient-providing reaction is reflected by microbial gene expression, probably through tipping-point phenomena. Communities of chemotrophic microbes work together to dissipate part of the energy present in their habitats. It follows that, in addition to triggering gene expression, the structure of microbial communities may be dictated, at least in part, by the state of reaction progress in a natural system. If so, there should be ways to use quantified states of reaction progress to predict the microbial activity as well as the compositions of microbial communities, and vice versa.

Coordinating biological, petrological, hydrological and geochemical sampling allows data integration and tests of hypotheses about the interplay of reaction progress, gene expression and community structure. As an example, genomic and phylogenetic studies can reveal the structure and composition of microbial communities. Snapshot views of this type can be related to the abiotic parts of the same system by calculating multicomponent reaction progress. Doing so is facilitated with inclusive, simultaneously collected compositional data from the natural system, and a thermodynamic model that incorporates minerals, aqueous solutions, organic compounds and microorganisms.

Current efforts to evaluate thermodynamic properties of microorganisms rely exclusively on thermodynamic properties of proteins (Dick and Shock, 2010). There is certainly more to organisms than their proteins. Nevertheless, close agreement is possible between microbial community structures obtained through environmental genomic data and those predicted by thermodynamic calculations. Perhaps the timing is right for a convergence of molecular biological data and geochemical data through the reference frame of reaction progress.

Dick, J.M. and Shock, E.L. (2010) Chemical equilibrium among microbial proteins in hot spring biofilms. PLoS Computational Biology (submitted).

An Integrated Approach to Study Energy Metabolism, Carbon Fixation, and Colonization Mechanisms in Chemosynthetic Microbial Communities at Deep-Sea Vents

Stefan Sievert[1], Jeff Seewald[1], Craig Taylor[1], Costantino Vetriani[2], Dionysis Foustoukos[3], Ramunas Stepanauskas[4]

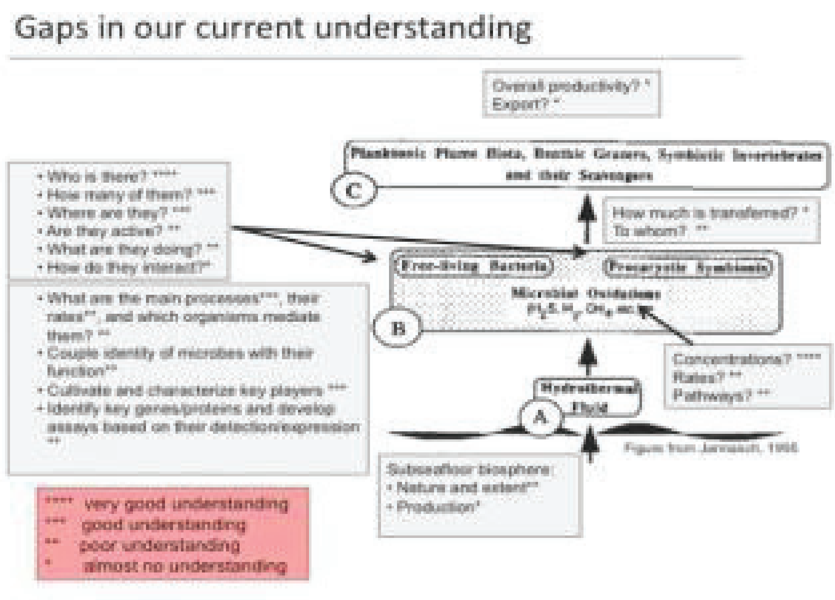
1. *Woods Hole Oceanographic Institution*
2. *Rutgers University*
3. *Geophysical Laboratory, Carnegie Institution of Washington*
4. *Bigelow Laboratory*

Chemolithoautotrophic microorganisms are at the nexus of hydrothermal systems by effectively transferring the energy from the geothermal source to the higher trophic levels. While the validity of this conceptual framework is well established at this point, there are still significant gaps in our understanding of the microbiology and biogeochemistry of deep-sea hydrothermal systems. This includes information on the diversity of chemolithoautotrophic microorganisms mediating critical reactions in different geothermal systems, the metabolic pathways used by the microbes, the rates of the catalyzed reactions, and the amount of organic carbon being produced. In particular, there is currently a notable lack of process-oriented studies that would allow us to assess the larger role of these ecosystems in global biogeochemical cycles. Important questions in this regard are:

A) How much and at what rates is carbon being produced? B) What are the dominant autotrophs? C) Which metabolic pathways are they using to conserve energy and to fix carbon? D) How efficiently is the energy being utilized and transformed into biomass? E) How do microbes attach to surfaces? F) How does community wide gene expression in fluid and biofilm communities compare? What is the role of biofilms for the functioning of the ecosystem?

While we can start integrating existing data to fill some of these gaps, ultimately a focused, interdisciplinary research program will be required to characterize the complexity of microbially-catalyzed processes at deep-sea vents at a qualitatively new level. Here we advocate to pursue an integrated approach that couples an assessment of taxonomic diversity using cultivation-dependent and -independent approaches with methodologies addressing genetic diversity, including metagenomics (genetic potential and diversity of community), single cell genomics (genetic potential and diversity of uncultured single cells), metatranscriptomics (identification and function of active community members), and metaproteomics (realized potential of community). To assess the functional component, these approaches would be combined with 1) measurement of in situ rates of chemoautotrophic production, 2) geochemical characterization of microbial habitats, and 3) shipboard incubations at in situ conditions (hypothesis testing under controlled conditions). This would provide unique insights into the functioning of deep-sea vent microbial communities and the constraints regulating the interactions between the microbes and their abiotic and biotic environment, ultimately enabling us to put these systems in a quantitative framework and thus a larger global context.

A.



B.

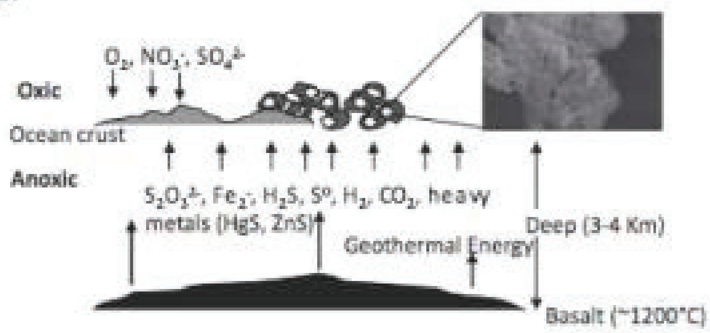


Figure 1. (A) Figure summarizing the gaps in our current understanding of deep-sea hydrothermal systems. Who is active and what are they doing (in-situ vs lab); Rates of processes; How do they interact; Biogeochemical relevance; subjective, but provides good framework to formulate research objectives. **(B)** Diagram of a hypothetical basalt-colonizing microbial community at the oxic/anoxic interface of a diffuse flow vent. A microbial community dominated by chemosynthetic *Epsilonproteobacteria* attaches to the basalt and establishes a biofilm. Colonizing bacteria are metabolically versatile and can use multiple energy sources and terminal electron acceptors.

Emerging patterns of global biogeography of Epsilonproteobacteria at deep-sea hydrothermal vents

Julie L Smith and Julie A Huber

1. Josephine Bay Paul Center for Comparative Molecular Biology and Evolution, Marine Biological Laboratory

Epsilonproteobacteria dominate the microbial community at many hydrothermal vent systems around the world. Over the last 15 years, a variety of molecular techniques have found Epsiloproteobacteria in almost all vent niches including microbial mats, diffuse fluids, and sulfide chimneys. Epsilonproteobacteria are also associated with Alvinella, Paralvinella, and Riftia tubeworms, various snails, and Kiwa crabs. These ubiquitous chemolithoautotrophs are involved in carbon, sulfur, and nitrogen cycling and play a potentially large role in the biogeochemical processes at hydrothermal vents.

The diverse Epsilonproteobacteria are comprised of both anaerobic hydrogen-oxidizing thermophiles and microaerobic sulfur-oxidizing mesophiles, which effectively straddle the redox gradient present at hydrothermal systems. At higher taxonomic levels, Epsilonproteobacteria are widely distributed at vent sites, however, individual species or strains show variable distribution within single vent chimneys (for example, Nakagawa et al. 2004, 2005, 2006) as well as among different diffuse fluids and chimneys within a hydrothermal field (for example, Huber et al. 2003, 2007, 2010, Opatkiewicz et al. 2009, Takai et al. 2008).

Several recent studies have begun to elucidate the relationships between the geochemical environment and the distribution of Epsilonproteobacteria. At Axial Seamount, the diversity of Epsilonproteobacteria was shown to be an important component in the structuring of the microbial communities and is linked to changes in the amount of sulfur, iron, and hydrogen in hydrothermal fluids (Opatkiewicz et al. 2009). At NW Rota Seamount, the dominant genera of Epsilonproteobacteria shifted from the thermophilic, anaerobic Caminibacter to a mix of Caminibacter and the mesophilic, microaerobic Sulfurimonas and Sulfurovum with a concordant decrease in the temperature of hydrothermal vent fluid (Davis & Moyer 2008). A comparison of 14 vents from 5 active seamounts in the Mariana Arc showed significant structuring of Epsilonproteobacteria among different vents and seamounts, but these differences were not correlated with either distance or chemical parameters, suggesting that further integrative studies are required to determine the underlying mechanisms affecting the biogeography of Epsilonproteobacteria.

We are currently working on a comparison of the NW Rota and West Mata Seamounts in the Western Pacific to Axial Seamount in the Eastern Pacific and look forward to integrating these studies with others from the Eastern Lau Spreading Center, the East Pacific Rise, and the Juan de Fuca Ridge.

Linking seafloor geology (volcanism, tectonism, and seafloor morphology) to crustal melt distribution and transport.

Adam Soule
Woods Hole Oceanographic Institution

Volcanic and tectonic features on the seafloor provide one of the most readily accessible features of mid-ocean ridge crests that may provide detailed information on the ‘state’ of the underlying magmatic system (e.g., length scales of segmentation, geochemical heterogeneity between and within melt lenses, degrees of over-pressure in magma bodies, stress conditions in the crust). The repose interval between eruptions, the volume of eruptions, the along- and across-axis extent of lava deposition, and the morphology and geochemistry of lavas, have been studied extensively at the EPR ISS, where we have benefited from observing a complete magmatic cycle culminating in the 2005-06 eruption. Comparable datasets are available for the Endeavor segment and the E. Lau spreading center.

The 2005-06 eruption of the EPR has provided a wealth of new information about how an individual magmatic event is manifest on the seafloor. Such information is crucial to understanding seafloor geologic features that integrate processes over 10s to 100s of such events. The along axis extent of the 2005-06 eruption was controlled by fine-scale segmentation of the ridge to a large degree, but in some cases extended through previously defined segment boundaries. In addition, the across-axis extents of the flows are variable, in some places reaching the edges of the neovolcanic zone and in others barely overtopping the AST [Soule et al., 2007]. The 2005-06 lava flows, which occurred at the predicted ~decadal repose interval for the EPR ISS, produced lavas at high-eruption rates generally, but with lower eruption rates towards the N. and S. ends of the eruption, presumably at segment boundaries [Fundis et al., 2010]. The eruptive vents within the AST resulted in remarkably little change to the dimensions of the trough, despite significant outpouring and accumulation of lava and possibly some amount of tectonic extension [Soule et al., 2009].

Of additional significance to the discussion of volcanic and tectonic processes at the ISSs are recent results (unpublished) from work I have conducted on the Mid-Atlantic Ridge where the style of volcanism (e.g., eruption rate and frequency) appears closely tied to the proximity to a centrally located mid-crustal magma body. Here the distribution of magma in the crust exhibits much sharper gradients than at most of the ISSs.

Based on observations from the ISSs and other MORs I am interested in exploring the following hypotheses and related questions linking seafloor geology and crustal magmatism:

1) Ridge crest morphology (in particular, axial summit troughs and axial valleys) reflects accumulated deformation due to magmatic dike injection balanced by varying degrees of volcanic accretion [e.g., Carbotte et al., 2006; Soule et al., 2009].

Does such a process include or preclude the occurrence of magmatic/tectonic cycles and at what time scale? What role does melt lens inflation/deflation play in shaping the ridge crest? What is the primary control on whether dike injection ultimately results in eruption on the seafloor and do those controlling parameters differ between ISSs, within ISSs, and between ridges of different spreading rate?

2) The style of eruption (low-eruption-rate, constructional volcanism vs. high-eruption rate, volcanic repaving) reflects the availability of melt in the crust and the proximity of eruptive vents to those melt sources.

Does variability in eruptive style correlate with seismic imaging of melt distribution? Can we discern changes in melt supply through time by examination of the volcanic products? Is spreading rate an accurate predictor of volcanic processes or do local variations in melt supply and tectonic stress provide stronger controls?

There is an opportunity at this meeting to strengthen the link between seafloor geology and crustal-scale geophysical observations at all the ISSs, in order to evaluate and refine proposed models of ocean crust construction, in particular the link between volcanic accretion and melt supply/melt lens segmentation.

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Endeavour Integrated Studies Site: Distribution of fin whales above hydrothermal vent fields. Extending ridge studies beyond "mantle to microbe" to encompass "mantle to mammal".

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From 2003-2006, we deployed an eight-station seafloor seismic network along a 10-km portion of the Endeavour segment of the Juan de Fuca ridge. In addition to microearthquakes, the network recorded an extensive data set of 20-Hz fin and blue whale calls. During the first year of operation we have identified more than 100,000 fin calls. The call rates vary seasonally with highest rates from November through January and very few calls from May to August (Soule et al.,2009). Previous work at this site has detected enhanced concentrations of zooplankton throughout the water column above the hydrothermal vent fields compared to sites 10 km away(Burd and Thomson 1995). As part of the project to investigate the hypothesis that whales are preferentially found above the hydrothermal vent fields, we have developed an algorithm to detect and track vocalizing whales that swim near the seismic network. The tracking algorithm can successfully track whales up to 10-15 km from the seismic network with little human intervention. The statistical analysis is focused on understanding the calling patterns and how these could be correlated with known diving patterns that have been linked to feeding (Croll, Acevedo-Gutierrez et al. 2001). For each track we measure the spatial length, total elapsed time, estimated velocity, the distribution of call intervals, and the distribution of call frequencies.

One application of this analysis would be to determine if gaps in calling occur preferentially along the ridge axis. This would help explore the possible trophic link between the mantle and the rest of the food chain because it is believed that whales feeding at depth do not vocalize. Studies have already been published that connect vent biota to zooplankton (Burd and Thomson 1995). This study utilizes data collected as part of a ridge study that expands the broader implications of ridge research while making immediate contributions to marine mammal science. Establishing this link would connect a food chain that encompasses the oldest and smallest microbes on the planet with some of the largest animals to have ever lived.

Integration and synthesis.
My current work is clearly relevant to R2K's broader objectives, but does not have an obvious fit into the meeting because there is no distinct water column theme. I participated in the Endeavour Tomography Experiment and will soon be attempting to create tomographic images with the seismic data we collected in summer 2009. My interest is in the magma plumbing system of the Endeavour Ridge and the associated hydrothermal vent system. The data set we have will provide insights into mantle flow, the distribution of hot and partially molten rock at mantle and crustal depths, segment-scale variations in crustal thickness, and their associated hydrothermal systems. The thematic groups I have chosen were picked to enhance my understanding of the questions surrounding the crustal structure and other magmatic hydrothermal features that can be imaged using seismic tomography.

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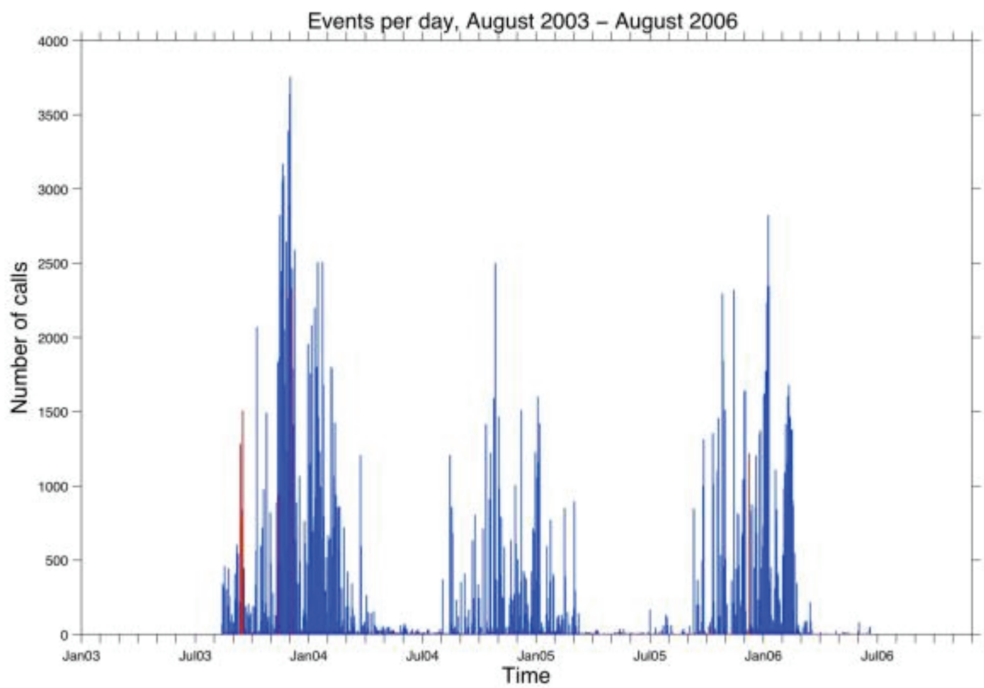
3yr Histogram of Whale Vocalizations at Endeavour Vent Field



A Hydrothermal Vent Biosampler for Filtration and Concentration of Hydrothermal Vent Fluids

Christina Stam, Moogega Cooper, Alberto Behar, Kasthuri Venkateswaran
Jet Propulsion Laboratory

As unexplored areas of the world slowly decline, precise and efficient instruments are needed to retrieve accurate data from remote subterranean aquatic habitats. Understanding the geothermal habitat of deep-sea environments can have strong implications of the upper boundary of life on Earth as well as in ex-traterrestrial locations. Since these habitats are poorly understood, the possibility of discovering new and rare species of microbes is a distinct possibility. The best ways to discover if life can exist in the harshest areas on Earth is by visiting and collecting data from these locations. By using, testing and perfecting the proper instruments, these tools can be then be utilized on other planets to challenge the understood/accepted notions of life.

The discovery of lush animal communities at deep-sea hydrothermal vents fundamentally changed the way we viewed life on Earth. Reduced hydrothermal fluids supply inorganic electron donors and acceptors to diverse microbial communities that span large gradients in temperature, energy availability, and physical parameters. Microbial habitats at deep-sea hydrothermal vents include animal symbioses, sulfide chimneys, microbial mats, sediments, the subseafloor, and vent fluids. There is little data regarding the microbial composition of high temperature fluids, mainly due to challenges in sample collection and processing. In-situ colonization devices used on high temperature vent orifices have successfully detected microbial cells at temperatures up to 180°C, and DNA has been extracted and quantified from high temperature vent fluids. However collection of pristine high temperature fluids from these locations cannot be guaranteed.

A novel hydrothermal vent biosampler (HVB) sampler was developed by the JPL Robotic Vehicles Group with input from the Biotechnology and Planetary Protection Group and experts from the Monterey Bay Aquatic Research Institute (MBARI), Scripps Institute of Oceanography (SIO) and Woods Hole Oceanographic Institute (WHOI). The HVB has been designed to collect large-volume samples of hydrothermal vent fluid untainted by the surrounding waters. The HVB performs in-situ filtering of hydrothermal vent fluids to concentrate a large volume of vent fluid to a smaller volume more suitable for transport. The unique aspect of the HVB is its lightweight, compact but efficient design. Standing at two feet tall with a mass of ~23kg, the HVB can withstand extreme temperatures (~400°C) and pressure (depths of 6500m). Using the unique bypass valve, the key mechanism to preventing contamination from surrounding water, the HVB can collect pure samples in excess of 10L of fluid which eventually is concentrated to a final volume of 200mL. The bypass pipe is used to flush the system to eliminate cross-contamination between samplings. By pumping fluid through the bypass valve before actual sampling, fluid from the previous sampling left in the intake nozzle through the four-way valve will be flushed. The four-way valve is then rotated to one of the three filter assemblies to begin sample collection. While the four-way valve acts to close off the front end of each filter assembly before and after sampling, a check-valve on the end of each filter assembly accomplishes the same on the back end. Each of the check valves is opened only when the four-way valve is aligned to its filter assembly and the pump is turned on. In-situ sensing devices have been positioned throughout the system to monitor real-time temperature and flow rates during sampling, ensuring that samples are collected from specific areas of interest (i.e. they are 'pristine').

The HVB has been deployed in various field locations that have included the hydrothermal vents in Iceland, Suiyo Seamount and Myojin Knoll vents in Japan, Rio Tinto in Spain, Hermosa Beach and cold seeps off of the Monterey Bay coast.

Microbial Biogeography and Biogeochemistry of Hydrothermal Plumes and Seafloor Rock Substrates

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Hydrothermal vents are conspicuous oases on the seafloor. The majority of microbial ecology studies of these systems have focused on life in warm fluids and on active chimneys. Less is known about hydrothermal plumes, especially in relation to how communities evolve with time within the plume. Likewise, interest in the cold rock substrates such as basalt and extinct hydrothermal chimneys has only recently come into focus. Additionally, little is known about the global distribution and dispersal of organisms that reside in plumes and on/in rocks.

Microbial communities in hydrothermal plumes are derived from two opposite end members- undiluted hydrothermal fluids ejected from vents and background ocean water. The chemical biome that results is thermally similar to the deep ocean, but replete with reduced compounds that are typically absent from those waters. This creates a unique biome that we know little about. Early work on the Juan de Fuca Ridge showed that there is a potential within plumes for carbon production rates generating equal amounts of carbon in situ through ammonia (Lam et al. 2004, 2008) and methane (de Angelis et al. 1993) oxidation within plumes to that falling from the photic zone. Interestingly, this ammonia oxidation appears to be carried out by ammonia oxidizing bacteria, not the ubiquitous ammonia oxidizing archaea, making hydrothermal plumes an interesting biome to study the competition between these organisms.

Recent work has begun to focus on defining microbial populations in plumes as a unique ecosystem (Dick et al. 2010, Sylvan et al. in prep). Further, work at 9°N EPR showed that plume communities can change drastically on the order of days, and, supporting work from the Juan de Fuca Ridge (e.g. Huber et al. 2007), Epsilonproteobacteria drive overall community diversity and structure in these plumes (Sylvan et al. in prep). Given the impact of hydrothermal plumes on deep sea geochemistry, it is important to understand the microbial populations and processes specifically within plumes in order to define their impact on deep ocean C, N and P cycling, as well as metal cycling.

Microbial populations on extinct hydrothermal chimneys and basalts have gained attention only recently (e.g. Kato et al 2010; Santelli et al 2008). These populations are unique from those in the overlying water column, and ecological succession is evident with age of the rock on basalts (Santelli et al. 2009) and active or inactive status on hydrothermal chimneys (Kato et al. 2010; Brazelton et al. 2010). Tag sequencing results from 9°N EPR recently provided an in depth look at bacterial succession and endemism on these two substrates. Interestingly, extinct chimney communities contain microbes known to cycle both reduced and oxidized forms of S and N on the same sample. Given the enormous global reservoir of extinct chimneys and basalts (both seafloor exposed and subsurface), these promise to continue providing fascinating and important discoveries within microbial ecology. In particular, the microbial weathering of these rocks, releasing elements into the water column (e.g. Edwards et al. 2004), and primary productivity rates (organic C production) are of interest for balancing global elemental budgets.

Crustal controls on the pattern of hydrothermal circulation at mid-ocean ridges

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One of the fundamental questions articulated in the original Ridge2000 Integrated Study Site implementation plans (e.g. http://www.ridge2000.org/science/downloads/endeavour/endeavour_ip.pdf) was "What are the major pathways and timescales of hydrothermal fluid circulation from recharge to discharge and what controls the location, intensity, magnitude, and style of hydrothermal venting along the segment?" Despite a number of successes in numerically simulating various aspects of hydrothermal circulation systems at midocean ridges (MORs), there has been little or no direct, or indeed indirect, observation of the pattern of subsurface hydrothermal circulation at a MOR spreading center. High resolution multibeam bathymetry has allowed us to document the location and volume of hydrothermal discharge structures and vent deposits within MORs and to define the relationship between these features and their tectonic and volcanic setting. Subsurface imaging of upflow zones, while difficult has been shown to produce discrete zones of reduced magnetization i.e. "magnetic burn–holes" that persist in the geologic record and provide clues as to the size and geometry of this part of the subsurface fluid pathway. In contrast, constraining where the zones of fluid recharge are is a more intrinsically difficult measurement/observation to document. Recent success with conductive heat flow measurements using bare-rock thermal blanket technology (Johnson et al., 2010) provides a possible method of addressing this latter issue. A prototype deployment of thermal blankets at the Main Endeavour Field on the Juan de Fuca produced results that imply that there are multiple scales of subsurface hydrothermal circulation present at the mid-ocean spreading center. At the scale of the axial rift valley or axial trough, there appears to be strong control from the bounding rift valley fault systems. The MEF thermal blanket survey shows a strong trend in conductive heat flux increasing from east to west across the rift axis with apparent recharge in the east and observed high temperature discharge on the western side. This across axis trend in heat flow mirrors the observed difference in depth to the seismically imaged top of the axial magma chamber, which is deeper in the east and shallows to the west. Superimposed on this overall pattern appears to be more local fluid circulation paths in annular-like patterns of recharge (low heat flow) around major vent areas and other less well-defined zones of local recharge at fault zones within the MEF rift. It is a clear that there is close interplay between hydrothermal circulation and parameters such as crustal structure, the depth of the magma chamber and tectonic stress in terms of faults and fissuring. Knowledge of the distribution of faults, fissures, the volcanic architecture and the depth to the axial magma chamber are all key parameters in driving the pattern of hydrothermal circulation at a MOR. In situ measurements of conductive heat flux using the thermal blanket instruments allows us to make this connection more definitive and to test more realistic 3D simulations of hydrothermal circulation in these environments.

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Tivey fig. Thermal blanket heat flow data across Endeavour rift valley

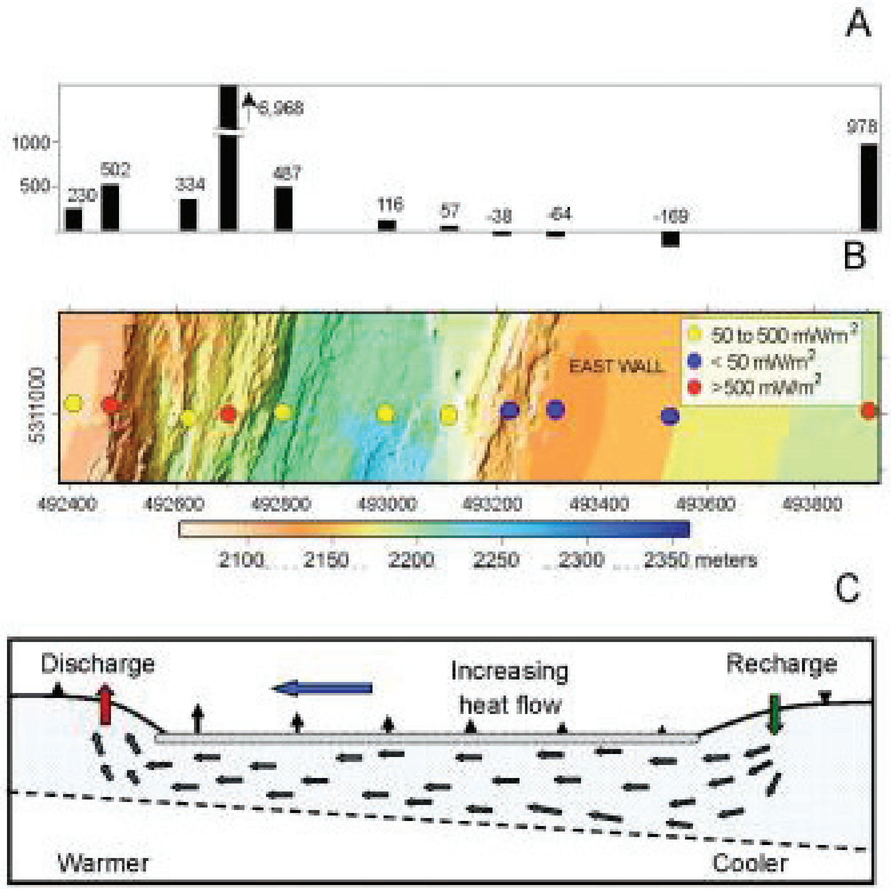

Figure 6: Panel a shows heat flow data from North Line; units are W/m2 and coordinated with the thermal blanket station positions below. The easternmost station lies in the topographic low east of the axial valley. **Panel B** shows station locations on a narrow swath of SM2000 bathymetry data. Circle diameter is proportional to the heat flow value except for red circles which are divided by 10 to allow plotting on same figure. **Panel C** shows interpretive cartoon of North Line data, with recharge occurring on the valley eastern boundary fault, sub-surface transport beneath the valley flow to discharge on the valley western boundary fault. Sloping dashed line represents the shallower magma chamber beneath the western side of the axial valley. Cartoon dimensions not to scale.

Integrating earthquake data from the East Pacific Rise ISS at 9°50'N

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From October 2003 through January 2007 an array of up to 9 OBSs continuously recorded earthquake activity near 9°50'N at the East Pacific Rise ISS. With hundreds of thousands of individual earthquakes recorded, the data processing task has been substantial. We anticipate that picking of events will be completed prior to the meeting with preliminary event locations being calculated in the months immediately following.

These data can provide information on the depth, width and temporal variability of the hydrothermal cracking front as well as possible zones of hydrothermal recharge and discharge. Work already published suggests that hydrothermal flow is dominantly along-axis with hydrothermal cells on the scale of about 2 km, and recharge occurring on-axis at locations of increased tectonic stress (and hence increase permeability) (Tolstoy et al., 2008). Additionally, work to date has shown that the earthquakes are occurring preferentially during times of increased tidal stress (Stroup et al., 2007) and that systematic spatial patterns in this triggering can be used to estimate permeability (Stroup et al., 2009; Crone et al., submitted). Stress and permeability within the hydrothermal cracking front are seen to be quite spatially heterogeneous (Bohnenstiehl et al, 2008; Crone et al., submitted). As processing of the entire data set is completed we expect to resolve temporal variability in properties of the cracking front as seismicity rates increased building toward an eruption (Tolstoy et al., 2006).

We hope to be able to integrate these interpreted properties and changes in the hydrothermal and magmatic system with geochemical, biological, geological and modeling work in the same area to build an integrated picture of a fast spreading ridge system. We also hope that detailed seismicity patterns from the fully processed data set will illuminate magmatic processes leading up to the eruption and help resolve differences between the geophysical and geochemical indicators of eruption timing.

An overarching goal of the R2K program included an integrated understanding of the mid-ocean ridge system from mantle to microbe. While much research is on-going at this site, and many collected data sets have yet to be fully analyzed, the East Pacific Rise ISS with it's bull's-eye at 9°50'N arguably represents the best studied and best understood section of mid-ocean ridge on the planet. As such it is an ideal site to define our current state of knowledge from mantle to microbe of an archetypal section of fast-spreading mid-ocean ridge.

Biogeochemistry of iron in hydrothermal plumes

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Hydrothermal venting associated with mid-ocean ridge (MOR) volcanism is globally widespread, and responsible for a dissolved iron (Fe) flux to the ocean that is approximately equal to all continental riverine runoff (1). For hydrothermal fluxes, it has long been assumed that most Fe is precipitated as inorganic forms via abiotic processes soon after entering the oceans as hydrothermal plumes. However, recent discoveries from isotopic, voltammetric, and spectroscopic studies prompt us to question these long held assumptions, and point to organic chemistry and biological processes as pivotal for Fe speciation at and transport from MORs (2-6). In particular, a potentially important role for dissolved and particulate organic matter in complexation of Fe in hydrothermal plumes is emerging. These discoveries are opening new avenues of inquiry regarding the properties of organic materials in hydrothermal plume systems and the biogeochemical processes active in the deep-ocean Fe cycle.

Biogeochemical cycling of Fe at MORs is a topic that represents an opportunity for the Ridge community. A critical and concise review of what is known about co-cycling of Fe, carbon, and sulfur at MORs would be valuable contribution because recent discoveries in this area highlight large knowledge gaps. A synthesis of the next big questions would help the community plan for integrated biogeochemical research activities in the context of existing and new programs (e.g. Geotraces and cabled observatories). Research conducted at East Pacific Rise 9-10 o N is particularly attractive for a review because the knowledge generated during R2K for this site is very rich. In addition, there are a number of researchers poised to publish new biogeochemistry research for plumes at EPR: John Breier (7), Christopher German, Olivier Rouxel, Katrina Edwards, Jason Sylvan, Sarah Bennett, and me (Brandy Toner).

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Geophysical Studies of Spreading Centers

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2. *University of Washington*

Overview: Tomographic imaging of spreading centers provides insights to mantle flow, the distribution of hot and partially molten rock at mantle and crustal depths, and segment-scale variations in crustal thickness. Such constraints can be used to study a range of problems, for example: 1) the origin of tectonic, magmatic and hydrothermal segmentation of spreading centers, 2) the nature of melt focusing and storage at mantle and crustal depths, and 3) the location and structure of the thermal boundary layer that separates the magmatic and hydrothermal systems. Seismic images – in combination with bathymetry, gravity and petrologic data – can also be used to infer the origins of axial depth anomalies, the temporal evolution of segment scale variations in melt production, and the degree to which magmatic differentiation may influence ridge crest processes.

We have conducted a series of tomographic experiments at fast-, intermediate- and slow-spreading ridges, including the EPR and Endeavour ISSs and the MAR near 35˚N. The results of these experiments allow us to compare and contrast mantle and crustal structure with spreading rate. There are some remarkable comparisons:

- Mantle divergence at fast- and slow-spreading ridges is not aligned with the spreading direction. Data from a recent experiment at the intermediate-rate Endeavour segment will further test this unexpected relation.
- Similarly, the axis of mantle upwelling at the EPR, and possibly the MAR, is not aligned with the ridge axis, suggesting that skew of mantle upwelling is related to spreading center segmentation.
- Melt focusing at fast- and intermediate-spreading ridges is not efficient. At both the EPR and the Endeavour segment, off-axis crustal magma bodies have been detected up to 20 km from the rise axis. In the case of the Endeavour, a preliminary analysis indicates that there are numerous off-axis crustal-level magmatic intrusions that underlie off-axis ridges and constructional volcanic features.
- At fast-spreading ridges, along-axis variations in axial depth are the result of crustal density anomalies which arise from systematic, along-axis variations in crystal fractionation depths. Whether or not this process is operative at slower spreading rates remains to be examined.

As expected, there are also well known differences in structure of spreading centers as a function of spreading rate; such as segment-scale variations in crustal thickness as well as the depth and shape of crustal magma bodies.

Integration and Synthesis: One avenue for integration and synthesis is to develop a series of overview papers that are suitable for a general audience of earth and life scientists, particularly those at the beginning stages of graduate school. Developing these papers in a way that separates "consensus" from "controversies" will allow the community and its newer members to evaluate progress as well as define directions for future research. With regards to future research, our ability to fully understand the "mantle to microbe" theme of R2K is limited by a lack of geophysical constraints on mantle structure, particularly at depths associated with primary melting and at a scale that can address the fundamental question of why ridges are segmented.

Role of Assimilation in Mid-Ocean Ridge Magmatism

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Results from our investigations at the 9°N overlapping spreading center may be important to numerous different disciplines within the MOR community and to several different ISS study sites. Although most geochemical variability in MOR basalts is consistent with low-pressure fractional crystallization of various mantle-derived parental melts, our geochemical data from MOR dacitic glasses suggest that assimilation of altered ocean crust is important in their petrogenesis and may be important in the formation of evolved gabbroic rocks and lavas at MOR in general. Thus, combining and comparing ideas of magma-rock interaction from our studies with observations from typical MORs may provide new insights into ocean spreading center magmatism.

Assimilation of crustal material requires latent heat from fractional crystallization to partially melt the surrounding wall rock. The heat required to melt the wall rock is highly variable depending on the temperature of the surrounding crust. Therefore, integration of our ideas and petrologic models of combined assimilation –fractional crystallization (AFC) processes with models of hydrothermal circulation on MOR is important in constraining thermal models for cooling of the ocean crust.

Finally, our study can be directly compared to and integrated with data collected other ISS study sites, particularly the Lau Spreading Center. High-silica lavas in MOR settings are rare compared to basaltic compositions; however, andesites and dacites have erupted on several ridges. Our studies suggest the petrogenesis of high-silica lavas at spreading centers requires both partial melting and assimilation of crustal material. The extensive petrologic and geochemical data from the 9°N OSC can be compared to the data obtained from at Lau Spreading Center to determine the role that assimilation plays in back arc settings and in the development of high-silica lavas in particular.

Seismicity and Upper-Crustal Structure of the Endeavour ISS

Robert Weekly
University of Washington

Research and Overview:
A suite of seismic investigations conducted at the Endeavour ISS provides insights to tectonic and magmatic processes associated with ridge-spreading and crustal accretion at intermediate-rate spreading segments. I have compiled a 38-month catalog of automatically located hypocenters recorded between 2003-6 using a unique ocean bottom seismometer (OBS) network [Weekly et al., 2008] that documents a substantial segment-wide decline in the number of earthquakes occurring per day following a sequence of seismic swarms located near the Endeavour – West Valley OSC during January and February 2005. Later this year, I will submit a paper that details the spatial-temporal characteristics of these swarms as the first chapter of my PhD thesis. In the paper, I posit that these swarms represent the terminus of a multi-year non-eruptive spreading event that initiated with the swarm sequence of 1999-2000 that was located by the SOSUS network on the southern portion of the Endeavour [Bohnenstiehl et al., 2004; Dziak et al., 2006]. I establish background seismicity levels of sub-regions of the Endeavour Segment prior to the 2005 swarms, detail the complex spatial-temporal distribution of earthquakes observed during the swarms, and show that the subsequent ~80% decrease in seismic activity is observed at both the vent-field and segment scale (see figure). Observed spatial-temporal hypocenter distributions and patterns of seismic moment release are consistent with non-eruptive magmatic extension near the southern tip of the West Valley Segment during the January swarm and along the northern portion of the Endeavour Segment during the February swarm. Additionally, I find increased seismicity levels around the Main Endeavour and High Rise fields during the January swarm, and near the High Rise and Salty Dawg fields during the February swarm. During each swarm, increases in vent field seismicity occur following a ~2.5 day delay of the swarm onset. Hooft et al [2010] propose that these delays are consistent with along-axis diffusion of a pore-fluid pressure perturbation in the upper crustal aquifer. The automated catalog I have created will facilitate further investigations including tidal triggering mechanisms, spatial and temporal patterns of seismic b-values, and rate-state modeling to better understand the relationship between stress change and swarm sequences.

Integration and Synthesis:
The focus of the second thesis chapter is to determine the three-dimensional seismic structure of the upper oceanic crust using compressional-wave travel-times collected from an August 2009 tomography experiment that comprised ~5,500 airgun shots recorded at 64 OBS sites. Analysis is still in its nascent stages, but my objective is to obtain a high-resolution image of the upper crust P-wave velocity structure using only waves that have turned in the upper crust. Ultimately, analysis will be expanded to include refracted arrivals from waves that interact with the top of the axial magma chamber. The upper-crust velocity model will detect variations in the structure of layer 2, which can be interpreted in terms of along- and cross-axis differences in volcanic accretion processes. Additionally, this model will provide tighter constraints on the structure of the thermal boundary layer separating the magma chamber from the upper crust. Correlating along-axis variations in thermal structure with variations in seismicity levels and hydrothermal fluid flux at particular vent fields will provide insights into how hydrothermal systems mine heat from a midcrustal magma source. This also has implications for inter- and intra-field variations in porosity structure. Obtaining a segment-scale model for the seismic velocity structure is critical to identifying the scale and intensity of ridge segmentation and melt distribution, which is one of the fundamental questions being addressed in several thematic working groups.

The final chapter of my thesis will combine the earthquake and tomography data to provide geophysical constraints on heat-transfer mechanisms within the hydrothermal uptake zone. An obvious application for the improved three-dimensional compressional-wave velocity model is to relocate the earthquakes. Additionally, I will use the method of joint hypocenter-velocity inversion to simultaneously improve uncertainties associated with shear-wave crustal velocity model and earthquake relocations. Improved constraints on the compressional- and shear-wave velocity structure in the upper crust will further improve the accuracy of earthquake depths and their position relative to the axial magma chamber in the upper crust.

For the upcoming R2K meeting, I am particularly interested in using the Events group to compare seismic characteristics of extensional plate-spreading events along different mid-ocean ridge segments. Continuing to make progress on synthesis of the recently collected tomographic data will also be one of my top priorities throughout the upcoming academic year, so meeting with attendees to discuss geophysical inversion strategies and improvement of starting velocity models will be another of my goals. The results of this inversion will be particularly appropriate for the Crustal Controls/OSC Magmatism group, so I will be keen on interacting with the community about expected levels of resolution and how other recently collected datasets might be used to complement the tomographic models.

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Linkages and decoupling in the magmatic system between mantle and seafloor

Scott White
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The "type" spreading ridges represented by the ISS's exhibit distinctive terrains among the ISS's and within single ISS sites. Integrated studies at the ISS's and a few other ridges reveal a relatively uniform progression from low magma supply rate to higher. The general progression is as follows: Large volcanic cones; complexes of smaller cones; smaller pillow ridges and isolated hummocks; low-relief lava flows and volcanic collapse troughs. Also, as spreading rates increase (seemingly independent of magma supply) ridge morphology transitions from high relief -- conical volcanic peaks -- to low-relief -- lava flow fields.

Combining detailed seafloor geological observations and previous geophysical imaging of the lower crust, possible connections between seafloor features and underlying melt bodies can be explored. The wide variability in the depth and shape of the melt bodies under the 9N OSC improves our ability to decipher linkages between surface volcanism and sub-surface melt. We find geomorphic boundaries are associated with changes in the mid- crustal melt sill, but appear form more in response to the dynamic crustal stress pattern at the OSC.

The locations of the youngest lavas based on surface appearance (A. Nunnery, MS thesis) and U-series dates (C. Waters & K. Sims, pers. comm.) fall into three different provinces. One is on-axis over a wide, robust melt sill. The second is clearly off-axis, where a ridge flank fault may be tapping the distal edge of a wide melt sill. The third is on a bathymetric ridge interpreted as the axis but has no underlying melt sill. However, most of this area has melt sills that are appearing to be uneruptible.

- No recent volcanism is observed over the plunging melt sill beneath the southern portion of the East Limb. Rather, recent volcanism occurs along the bathymetric ridge nearest the overlap basin.
- An unusual abundance of andesites and dacites erupt on-axis on the northern portion of the East Limb.

The study of the 9N OSC offers two lessons applicable to the study of other ridges. First as a cautionary example on over-interpreting the meaning of sub-surface melt bodies from geophysics alone. Much more must be learned about the properties of the melt bodies before their effects on seafloor processes can be predicted. Second, is that crustal deformation seems to play the dominant role in creating the seafloor geology even in many magma-rich places. For example, analysis of the eruption patterns on the EPR in 1991 and 2005-06 suggests pre-existing segmentation controls subsequent eruptions.

Seismological Studies of Magma-Hydrothermal Interactions

William Wilcock
University of Washington

My recent ridge-related fieldwork has been exclusively focused on the Endeavour Segment of the Juan de Fuca Ridge. Here we deployed a small high-quality seismic network from 2003-2006 to monitor microearthquakes. At the vent field scale, the results show a strong correlation between seismicity rates and hydrothermal heat fluxes measured by other researchers (see attached Figure) and document a seismicity pattern that is consistent with the expected signature of steady magma injection beneath the most hydrothermally vigorous fields [Wilcock et al., 2009]. At the segment scale, two swarms in January and February 2005 are consistent with non-eruptive magmatic extension on the southward extension of the West Valley propagator and the northern portion of the Endeavour Ridge, respectively [Hooft et al., 2010; Weekly et al., 2008]. Seismicity rates on the Endeavour dropped dramatically following these events, leading one of my students to conclude that the swarms marked the end of a 6-year spreading event that started in 1999 and ruptured the whole segment [Weekly et al., 2008]. One year ago we completed an ambitious tomography experiment that comprised ~5500 shots recorded at 64 OBS sites at 3 nested scales – those of the whole segment, the upper-crustal axial magma chamber (AMC) reflector and the vent fields. The analysis is still in the early stages but will provide new constraints on the distribution and nature of melt supply from the mantle to the crust, the magmatic structure of the lower crust and its linkages to the presence/absence of an AMC, and the structure of the thermal boundary layer and hydrothermally altered/fractured zone overlying the AMC. Amongst other objectives, the combination of tomographic and microearthquake data should provide a unique opportunity to better understand physical processes in the magmatic-hydrothermal interaction zone.

Integration and Synthesis (I&S)

I have a number of personal goals for this workshop. (1) I have had a long-standing interest in event plumes and I believe that recent observations in the Eastern Pacific provide an opportunity to refine and evaluate competing models for their formation. (2) Much of my research is currently focused on understanding the process by which hydrothermal systems uptake magmatic heat. Geophysical constraints require that the magmatic systems are separated from hydrothermal systems by a thin (~10-m-thick) conductive boundary layer while the geochemical observations constrain the characteristics of an overlying region where the fluids react with the rock. I think these two different perspectives focusing on the heat-uptake and reaction zones are not always very well reconciled and I think there is an opportunity for I&S. (3) I teach a class to seniors at the UW on Marine Geology and Geophysics which focuses on the creation, evolution and destruction of ocean basins and thus devotes significant time to oceanic spreading centers. Relative to their importance, I think mid-ocean ridges are grossly underrepresented in undergraduate geosciences education, perhaps because many ridge researchers have been located in research institutions or in university departments with limited undergraduate interaction. I am interested in ideas for how this might be rectified.

In the longer term, I think R2K needs to recognize that while the program might be ending, research on ridges should not and that our I&S efforts need to set the stage for new experiments. In the field of seismology, the R/V Marcus G. Langseth and the expanding capabilities of US National Ocean Bottom Seismography Instrument Pool are providing new capabilities to conduct 3-D MCS experiments and active source and passive source tomography experiments of unprecedented scope and resolution. At the Endeavour and Axial Seamount the development of cabled observatories provides a unique opportunity for long term seismic and hydrothermal monitoring that should be complemented by autonomous and mooring supported experiments elsewhere. While I have no expertise in the area of chemical and biological studies, I am pretty sure that new sensors and techniques are providing similarly exciting opportunities in these fields. These new opportunities are expensive and may require and approach whereby field experiments are increasingly justified and staged as coordinated community experiments (a trend that to some extent commenced with the Lau ISS and which is being discussed by the marine seismic community). Our community needs to figure out how to become a Big Science.

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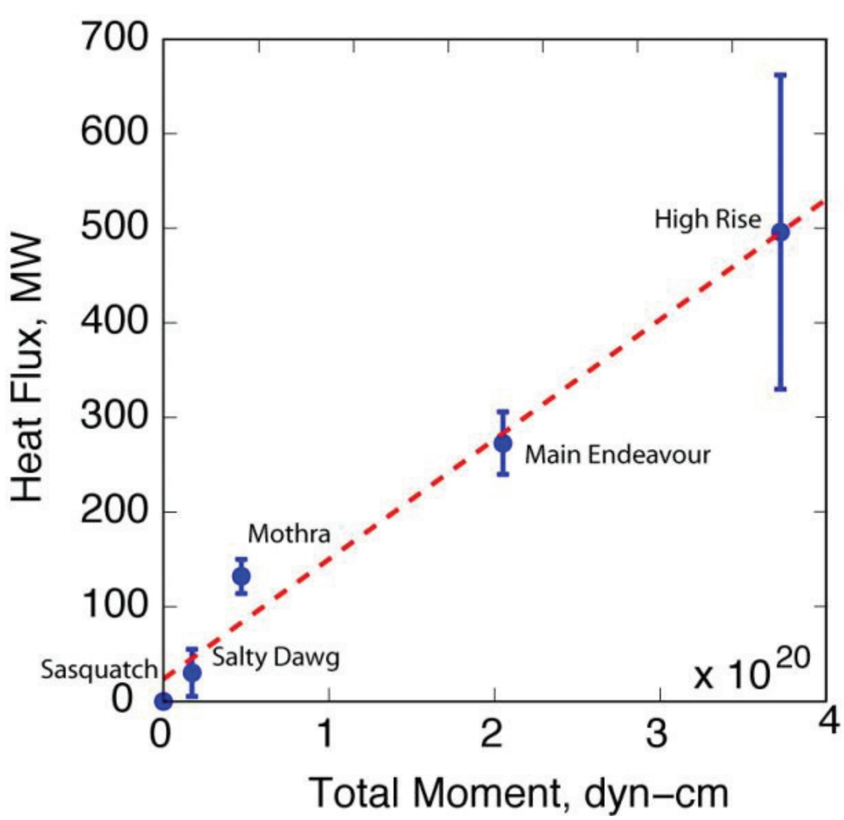
Figure. Plot of the seismic moment release beneath each Endeavour vent field for summer 2003 – summer 2004 versus the heat flux measured in summer 2004 [Thompson et al., 2005].



Posters Table of Contents

Genomic insights into deep-sea hydrothermal plumes

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Hydrothermal plumes serve as important habitats for chemolithoautotrophic microbial communities that mediate the fate of hydrothermal inputs into the deep-sea. Although past studies have shown enhanced biological activity and biogeochemistry in hydrothermal plumes, little is known about the microorganisms involved.

Here we highlight the potential of metagenomics and metatranscriptomics for tracking microbiological and biogeochemical processes in plumes, and ultimately for advancing our understanding of the transfer of material from vents to oceans.

First, we report the analyses of microbial communities from the Guaymas Basin hydrothermal plume. Assembly of ~2 million 454 Titanium metagenomic reads produced near complete genomes of SUP05-like gammaproteobacteria, Methylomonas-like gammaproteobacteria, SAR 324-like Deltaproteobacteria, and Crenarchaeota. Analyses of ~3 million transcriptomic reads revealed 85% of them to be rRNA, which provides a deep view of the activity of different taxa. Additionally, comparison of protein-coding transcripts observed in plume and background highlighted overabundance of transcripts encoding sulfur oxidation, electron transport proteins and a gene coding for a multi copper oxidase potentially involved in manganese(II) oxidation.

Second, we describe recently initiated work aimed at characterizing microbiology and geochemistry of rising hydrothermal plumes along the Eastern Lau Spreading Center. Work is underway to use high-throughput pyrosequencing of 16S rRNA genes and metagenomics to reveal plume microbial community structure and potential function. Integration of this data with geochemical and mineralogical analyses will provide insights into the co-evolution of microbiology and geochemistry in rising plumes of diverse geologic setting.

Overall, our results will seek to highlight the microorganisms present and active in hydrothermal plumes and determine their roles in plume biogeochemistry.

Contributions to Integration and Synthesis:
We intend to use a combination of genomics, geochemistry, and mineralogy to study biotic-abiotic interactions, microbial mediation of biogeochemical reactions, particle formation and fate of hydrothermal inputs. Our work would integrate results from different vent sites along the Eastern lau spreading center representing a natural geochemical and lithological gradient and enable us to compare the geomicrobiology of the background deep-sea, sea floor and rising and neutrally buoyant plumes. While there have been a number of hydrothermal plume models, they solely incorporate abiotic interactions. To synthesize new findings of microbial processes and abiotic-biotic interactions in hydrothermal plumes, we are developing a hydrothermal plume model that couples hydrothermal fluid flow, mixing with ambient sea water, particle formation, biogeochemical reactions and microbial processes.

Global distribution of hydrothermal vent fields

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2. NOAA PMEL

Since the visual confirmation of deep seafloor hot springs, or hydrothermal vents, at the Galapagos Rift in 1977, submarine hydrothermal activity has been studied in all ocean basins, at a wide range in depth, and in a variety of volcanic and tectonic settings. In 2004 Baker and German undertook a review of the global distribution of hydrothermal vent fields (in Mid-Ocean Ridges: Hydrothermal Interactions Between the Lithosphere and Oceans, Geophysical Monograph Series 148, German, C.R. et al., eds., 245-266). As InterRidge Coordinator, Beaulieu combined Baker's global listings of vent fields with several other listings, incorporated new findings including from commercial industry, and in 2010 released the revised InterRidge Global Database of Active Submarine Hydrothermal Vent Fields (http://www.interridge.org/IRvents). The database provides a comprehensive listing of confirmed (visually, from seafloor observations) and inferred (based on water column measurements and/or seafloor sampling) active hydrothermal fields. As of the end of 2009, there were 229 confirmed active submarine hydrothermal vent fields, with 47% at mid-ocean ridges, 27% at volcanic arcs, 21% at back-arc spreading centers, and 5% intra-plate and other tectonic settings. Thirty-five percent of the confirmed active vent fields were confirmed in the decade 2000-2009, with a relatively large number of these at volcanic arcs. The total number of inferred active vent fields at the end of 2009 was 273, more than double the number in Baker and German (2004) and reflective of the increased efforts in systematic surveys for detection of hydrothermal plumes. Although many of the recent discoveries were made by academic researchers, an increasing number of discoveries are due to national and commercial interests in seafloor mineral exploration.

Contributions to Integration and Synthesis:

The Ridge 2000 Program focuses on three Integrated Studies Sites, two of which are representative of mid-ocean ridge tectonic settings at intermediate (Juan de Fuca, Endeavour) and fast (EPR) spreading rates, and the other a back-arc spreading center (Lau). The revised global map presented in this poster shows the distribution of all known hydrothermal vent fields in all volcanic and tectonic settings, and will be useful to display during the R2K Meeting for a geographic perspective. The database, available online in several formats, includes additional information such as spreading rate and temperature that may be useful in comparing to R2K ISS vent fields.

Snail Endosymbiont Type Follows Hydrothermal Vent Chemistry In The Eastern Lau Spreading Center

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2. Department of Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution

Gastropods of the genus Alviniconcha are found at hydrothermal vent fields in the Western Pacific, and have been reported to associate with either γ- or ε-Proteobacterial endosymbionts. These symbionts harness energy from the oxidation of chemicals in vent fluid to fix inorganic carbon and are the primary source of nutrition for the host. An extensive sampling effort from a recent expedition to the Eastern Lau Spreading Center (ELSC) has revealed that Alviniconcha with symbionts of both types are found at vent fields along the ridge and that the dominance of each type at a vent field relates to the geology and geochemistry of that site. We collected 266 Alviniconcha individuals from four vent fields along the spreading center (30-140km apart) which span the north-south transition from fast spreading, basalt-hosted vent fields to slower spreading, andesite-hosted fields. Vent fluids from each field were also analyzed for the abundances of aqueous volatile and non-volatile species. The symbionts of all collected Alviniconcha were genotyped using restriction fragment length polymorphism analysis of the 16S rRNA gene. Individuals were found to host one of three symbiont genotypes (two γ- and one ε-Proteobacteria) and 16S rRNA genes from representative individuals of each type were sequenced. We found that the two northern-most sites (basalt) were dominated by individuals with the ε-Proteobacterial symbiont, while the two southern sites (andesite) were dominated by individuals hosting one of the two γ-Proteobacterial symbionts. This pattern also corresponds to differences in the aqueous chemistry of the vent fluids along the spreading center: in particular, we have measured higher concentrations of hydrogen and hydrogen sulfide in the vent fluids at the northern sites than in the fluids of the southern sites. Thus, vent chemistry may be influencing the dominance of each symbiont type along the ELSC.

Contributions to Integration and Synthesis:

This work makes links between vent field geology and geochemistry and the abundance of different chemosynthetic associations (Alviniconcha spp. and two classes of endosymbionts) at that field. Thus, it synthesizes measurements of physicochemical parameters at different vent fields with a survey of the distribution of symbiotic associations, enabling us to better understand the ecology and evolution of chemosynthetic symbioses at hydrothermal vents.

Denitrication as the dominant N-elimination process in hydrothermal vents of the Juan de Fuca Ridge, North-East Pacific Ocean

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5. Max Planck Institute for Marine Microbiology (MPI), Department of Biogeochemistry

Nitrogen (N) is an essential macronutrient for all organisms. Therefore, oceanic N sinks, removing bio-available (or fixed) N, ultimately affect primary productivity. The relative importance of the two main N-elimination pathways, i.e. denitrification and anaerobic ammonium oxidation (anammox) in different oceanic environments and in the global ocean is still a matter of debate. Little is known about metabolic processes and bacterially-mediated N-cycle dynamics occurring in the subsurface biosphere of hydrothermal vent systems. Rates of major N-elimination processes have never directly been quantified in diffuse vent fluids. In this study, we measured rates of major fixed N-elimination pathways (denitrification, anammox) and dissimilative nitrate reduction to ammonium (DNRA) in hydrothermal vent fluids at 7 different sites on the Juan de Fuca Ridge using 15N-label incubations. We also measured the isotopic composition of dissolved inorganic nitrogen (DIN) (nitrate and ammonium) and N2O concentrations, an intermediate product of denitrification. All samples were collected during a cruise in the Northeast Pacific Ocean onboard the R/V Atlantis in June 2009. Elevated nitrate δ15N and δ18O in the high-Mg2+, low-T vent fluids associated with a [NO3-] decrease is indicative of dissimilatory (denitrification) or assimilatory (nitrate uptake) nitrate consumption. Denitrification rates in hydrothermal vent fluids at Axial Volcano and Endeavour Segment are high and variable between sites, ranging from ~30 (Fairy Castle, Main Endeavour Field) to 1040 (Hermosa, Axial Volcano) nM/day. [N2O] ranged between ~0-430 nM, with no observable correlation with denitrification rates. Anammox rates are below ~5 nM/day at 3 sites and not detectable at all other sites. DNRA rates are ranging from ~0 to 200 nM/day. These results suggest that denitrification is by far the dominant N sink in hydrothermal vent fluids of the Juan de Fuca Ridge. In agreement with previous studies, our results suggest that, at least in sulfidic waters, nitrate reduction by bacteria (possibly associated with sulphide oxidation) can out-compete anammox bacteria. Future microbiological work will evaluate the identity and abundance of the denitrifying bacteria present in vent fluids.

Contributions to Integration and Synthesis:

As mentioned above, Nitrogen (N) is an essential macronutrient for all living organisms. This work represents the first rate measurements of N-cycle processes in diffuse hydrothermal vent fluids. This research is crucial for integration and synthesis at the R2K meeting because it allows to better understand the fluxes or N in the subsurface biosphere of hydrothermal vent systems, with important implications for chemosynthetic primary productivity.

Evaluation of the Molecular Diversity of samples collected using a Hydrothermal Vent Biosampler

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Jet Propulsion Laboratory

A novel hydrothermal vent biosampler (HVB) sampler was developed by the JPL Robotic Vehicles Group with input from the Biotechnology and Planetary Protection Group and experts from the Monterey Bay Aquatic Research Institute (MBARI), Scripps Institute of Oceanography (SIO) and Woods Hole Oceanographic Institute (WHOI). The HVB has been designed to collect large-volume samples of hydrothermal vent fluid untainted by the surrounding waters. The HVB both filters and concentrates large volumes of vent fluid. In-situ sensing devices have been positioned throughout the system to monitor real-time temperature and flow rates during sampling, ensuring that samples are collected within the target environmental conditions. If a temperature deviation occurs from the desired level, the collected water is released through the bypass system until the desired temperature is reached (i.e. they are 'pristine').

For this study, the HVB was deployed on the bank of Lynx Pond in Rio Tinto. The intake line was inserted into the selected site of the pond through visual guidance. Additionally, temperature and chemical sensors were available to further pin-point a precise sampling area. The water was pumped through the bypass pipe and flushed through the flow outlet line. In between sample collections, the field site water was pumped through the bypass to prevent cross-contamination between sampling events. After bypass, the pump was then rotated to one of three sample collection valves and pumped through the filtration system for 10 min. The first two samples were collected from the Lynx pond and the third sample was collected from Jana's stream. The 90, 60 and 7 µm filters were aseptically removed from the HVB and placed individually in sterile conical tubes. Each individual filter was immersed in a suitable buffer and sonicated for 2 min at a frequency of 25 kHz. The biomatter samples recovered from the filters were concentrated to a final volume of <500 µL using a 50 kDa filter. DNA was isolated from each concentrated sample, and PCR or qPCR was performed using universal primers targeting bacterial 16S rRNA, eukaryotic 18S SSU rRNA and archaeal 16S rRNA.

Excellent PCR amplification of Eukaryotic DNA was obtained from the filters. Bacterial DNA qPCR concentrations ranged from 102 – 104 copy numbers. Cloning/sequencing, PhyloChip and MycoChip analyses will be used to determine the microbial diversity of the samples.

The high acidity and iron content of the Rio Tinto waters did not impact performance of the HVB and it proved to be robust and versatile in collecting samples from extreme environments of astrobiological relevance

Contributions to Integration and Synthesis:
Development of technologies to sample from hydrothermal vents

Uranium-series disequilibria of inflated sections of the Juan de Fuca Ridge: Implications for mantle melting

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U-Th disequilibria are reported for the two inflated portions (defined by bathymetric highs) of the Juan de Fuca Ridge (JdFR): Axial Seamount and the northern Endeavour segment. Both have broad axis-centered bathymetric plateaus, commonly attributed to the influence of the adjacent Heckle and Cobb melt anomalies, respectively. We explore structural and geochemical contrasts between them that imply fundamental differences in magma plumbing and/or transport processes.

The depth to the axial magma chamber (AMC) within the JdFR crust is shallowest beneath Axial Seamount and deepest and most variable beneath Endeavour. Lavas from Endeavour include the most enriched and diverse compositions of the JdFR. Endeavour N-MORBs are most similar to Axial basalts in K2O/TiO2, La/Yb, Na8, and Fe8 although most Axial basalts have lower MgO. Major element trends suggest clinopyroxene saturation at higher MgO at Endeavour. Additional basalt types from Endeavour (i.e., those with K2O/TiO2 >0.15), the West Valley segment to the north, and Southwest Seamount to the west share similar enrichments in incompatible trace elements (Th, Nb) and radiogenic-Pb. Similar characteristics are absent from basalts from the adjacent Heck and Heckle seamount chains, which are highly-depleted N-MORBs, precluding the hypothesis that thickened and inflated crust at Endeavour is associated with increased melt supply due to transit over the seamount source. In contrast, Axial basalts are more chemically homogeneous, and share selected geochemical characteristics with the adjacent Cobb seamount chain.

New uranium-series data suggest fundamental differences in melting parameters between inflated and non-inflated portions of the JdFR. Average Th/U at Endeavour (3.03 ± 6, n=10) is nearly indistinguishable from Axial (2.83 ± 9, n=17), but both are distinct from elsewhere on the JdFR (~2.1-2.5). That is, basalts erupted from regions of inflated crust have higher Th/U. Despite high overall compositional diversity in Endeavour basalts, Th/U variance is low, as in Axial basalts. However, there are differences in (230Th)/(232Th). Seventeen samples from Axial Seamount have (230Th)/(232Th) <1.22, the lowest on the JdFR axis. The range at Endeavour is 1.26-1.35, and highest in N-MORB. (230Th)-excesses [(230Th)/(238U) >1] are much higher at Endeavour (20-30%) than Axial Seamount (5-20%) and the rest of the JdFR (8-14%) but more similar to values of the adjacent Gorda Ridge to the south (up to ~25%). If differences in melt column characteristics (i.e., porosity, lithology, potential temperature) are similar along the JdFR, then ingrowth melt models predict slower upwelling of mantle-derived melts (e.g., longer residence time in the melt column) at Endeavour. Alternatively, Endeavour lavas may be generated from a more pyroxenitic (lherzolite) mantle where large degrees of disequilibria can be generated.

Contributions to Integration and Synthesis:
This work details the integration of our geological (mapping), geochemical, volcanological, and preliminary geochronological study of the Juan de Fuca Ridge. Here we explore the geochemical systematics of the bathymetrically inflated sections to extract information on mantle melting parameters; these sections also have important geophysical contrasts.

Preliminary model of hydrothermal circulation at East Pacific Rise 9°50 N constrained by thermal, chemical, and seismic data

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The East Pacific Rise 9°50' N area has been a subject of intense multidisciplinary study for two decades. Currently, numerous data sets provide strong constraints on magmatic activity, on the depth and flow geometry of hydrothermal circulation, on the thermal and chemical evolution of vent fluids, and on the evolution of biological communities. These data together provide strong constraints on acceptable mathematical models of the magma-hydrothermal system.

Using a combination of thermal, geochemical and seismic data as constraints [1,2,3], we develop a preliminary model hydrothermal circulation along approximately 2 km of ridge axis from TWP to the Bio9 vent complex. We first use a single-pass model [4] together with a heat flux estimate of 160MW and average vent temperature of 370°C to obtain a mass flux of » 80 kg/s, a conductive boundary layer thickness of » 10 m, and a permeability of the discharge zone ranging between 3 x10-12 and 3 x 10-13 m2. Secondly, we use a two-limb single-pass model using the observed partitioning of heat flow between focused and diffuse discharge [5] and vent chemistry [2] to show that at least 80% of the total heat flow comes from magma sources. As a result of these analyses, we find that the sub-axial magma chamber must be actively replenished on a decadal time scale, which is consistent with recent petrological data. Finally, the preliminary model suggests that the seismically inferred recharge zone may not be large enough to carry all the flow without clogging as a result of anhydrite precipitation. Further analysis of this issue will require numerical modeling.

1. Ramondenc et al. (2006) EPSL, 245, 487-497.
2. Von Damm and Lilley (2004) Geophys. Monogr. 144, 245-268.
3. Tolstoy et al. (2008) Nature, 451, 181-184.
4. Lowell and Germaonvich (2004) Geophys. Monogr. 148, 219-244.
5. Germanovich et al. (2010) J. Geophys. Res.

Contributions to Integration and Synthesis:

The global importance of seafloor hydrothermal processes and the interplay among magma transport, crustal structure, seawater circulation, and biogeochemical processes have resulted in focused research at a few integrated study sites, through a number of coordinated, integrated, interdisciplinary experiments to develop focused, quantitative, whole system models for these sites.One of these sites is the 9°10 N region of the East Pacific Rise (EPR), particularly near 9°50 N.We model hydrothermal circulation at the East Pacific Rise ISS site.

Basalt mineral oxidation by ocean crust bacteria (Scientific Program ISME-13, Seattle, USA, 22-27 August 2010)

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Ocean crust microbial biomass is more substantial than that of microbial life in the deep sea. The most likely source of energy for sustaining sub-seafloor microbial populations comes from redox-active iron that is slowly released from basalt glasses and minerals, including olivine and fayalite. Fluid flow creates a transport mechanism for microbes to colonize new crust as it forms, and it has been shown that older crusts have the highest biomass and greatest alteration. The main purpose of this study was to determine which minerals in basalt are preferentially colonized by bacteria, and why.

A variety of igneous minerals and glasses were incubated in microbial flow cells for four years in IODP borehole site 1301A on the eastern flank of the Juan de Fuca ridge. The total number of cells on each mineral were stained with DAPI and counted using epifluorescent microscopy. Oligotrophic mesophiles and thermophiles were isolated on marine R2A plates and reported as colony forming units (CFUs) per gram of mineral. Isolate 3d.6 from fayalite was incubated in olivine cultures to determine iron oxidation and reduction capabilities.

Total cell counts reflect a preference among bacteria for iron-rich minerals from basalt. Thermophilic bacteria were isolated from olivine and fayalite only, and mesophilic bacteria were present in larger numbers on the iron-rich minerals. Our results also indicate iron oxidation of olivine minerals by isolate 3d.6. This bacteria is was not found to be capable of iron reduction in olivine cultures with either lactate, acetate, succinate, or pyruvate.

Our results suggest iron is an important source of redox energy in the ocean crust which helps support a greater biomass. Our results also indicate that olivine is capable of supporting iron-oxidizing populations of bacteria.

Changes in the formation of axial volcanic edifices in response to changes in magma supply rate

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The spatial and abundance distributions of volcanic edifices along mid-ocean ridges have a well known correlation with spreading rate. Along slow spreading centers, volcanic edifices are normally distributed about the segment center. Volcanic edifices along fast spreading centers have the opposing trend, i.e. edifices form primarily at the ends of segments. Along ridges affected by plumes and in back arc basins, the spatial and abundance distributions of volcanic edifices differ from that observed at normal ridges of the same spreading rate. This suggests that magma supply rate may control the spatial and abundance distribution of volcanic edifices. Recent geophysical and geochemical studies along the Juan de Fuca Ridge (JdFR), Southeast Indian Ridge (SEIR) and the Valu Fa (VF) and Eastern Lau Spreading Centers (ELSC) put tight constraints on crustal thickness, making it possible investigate the effect of magma budget and axial morphology on the formation of volcanic edifices. Volcanic edifices are described according to their volume, shape (their height to basal radius ratio) and their location relative to the end or center of a segment (abundance distribution). Edifices along the SEIR and JdFR show little variation with changes in axial morphology at relatively constant spreading rates. Results for VF and ELSC are what we expect for changes in spreading rate, not axial morphology. Our study suggests that the formation of volcanic edifices at the SEIR, JdFR, VF and ELSC are not significantly influenced by magma supply rate.

Contributions to Integration and Synthesis:

This work utilizes multibeam bathymetry, geochemical analyses and crustal thickness approximations obtained from two of the three study sites (Lau and Juan de Fuca) and compares those results to another intermediate spreading rate ridge (Southeast Indian Ridge). We are also attempting to compare segmentation patterns represented by the location, size and shape of volcanic edifices in the neovolcanic zone to specific mantle attributes, such as abnormal magma supply rates.

Age of the Endeavour Vent Field

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We present new geochronological studies of the hydrothermal sulfides within the Endeavour ISS. Results from Ra-226/Ba geochronology in sulfide-associated barite indicate that high-T venting within the current axial valley was likely initiated <5,000 years ago. Previous geochronological studies of hydrothermal sulfides from the Juan de Fuca Ridge have focused on rates of chimney growth and sulfide accumulation using short-lived isotopes (e.g. Pb-210 (half-life of 22.3 yrs.), Ra-228 (half-life of 5.7 yrs.) and Th-228 (half-life of 1.9 yrs.)) (Kadko et al., 1985; Grasty et al, 1988; Kim and McMurtry, 1991; Reyes et al., 1995). These studies represent snapshots of venting activity over short timescales (<10 years). The examination of processes that occur over the lifespan of an entire vent field require the use of radioisotopes with longer half-lives. Radium-226 (half-life of 1,600 years) occurs in high abundances in hydrothermal barite, which precipitates in conjunction with sulfide minerals on the seafloor. Measurements of the Ra-226/Ba ratios of hydrothermal barite provide a chronometer that allows for the determination of the absolute ages of sulfides between ~300 to 20,000 years old. Age calculations of 42 sulfides from Mothra to Sasquatch show a range of ages from present to a maximum of 2,500 years. This maximum calculated age represents a minimum age of venting at Endeavour.

Contributions to Integration and Synthesis:

Information on the ages of hydrothermal sulfides and longevity of venting at Endeavour may have profound implications for numerous topics of investigation within the ISS. Specific areas where these data may be applicable for integration and synthesis include, but are not limited to: • Temporal changes in vent fluid chemistry and fluxes • Accumulation rates of sulfide • Episodicity of venting and spatial constraints on past venting activity • Temporal constraints on biological colonization and evolution • Correlation between hydrothermal venting and the volcanic/tectonic history of the current axial valley I envisage that these data will be of particular interest to participants in the following Thematic Working Groups: • Spatial and temporal variation in chemistry and heat fluxes in hydrothermal systems, including chronic plumes • Seafloor tectonic and volcanic events and responses, including event plumes • Biogeochemical processes in deep-sea hydrothermal systems • Crustal controls on magma reservoirs and ocean spreading center magmatism

Iron respiration as a common endolithic metabolism among hyperthermophiles in mildly reducing hydrothermal vents

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Many basalt-hosted deep-sea hydrothermal vents have mildly reducing, mildly acidic conditions and porous mineral deposits, which makes them ideal habitats for certain microbes that respire metal oxides. At our main study sites, the Endeavour Segment and Axial Volcano on the Juan de Fuca Ridge, hyperthermophilic Fe(III) oxide reducers were cultured from the interior of all five active sulfide structures sampled and were more abundant than hyperthermophilic methanogens. H2 oxidation coupled with iron reduction, while highly favorable thermodynamically, was presumed to be insignificant in metabolism models due to iron oxide's insolubility and limited accessibility. However, spectroscopy and petrology analyses of sulfide samples from our study sites show considerable ferric mineral substrates present in pore space surfaces due to seawater intrusion. Hyperthermophilic iron oxide reducers interact with ferrihydrite (Fe(OH)3) through direct contact via cell wall invaginations and pili attachment. Some hyperthermophiles reduce ferrihydrite to magnetite (Fe3O4), perhaps through a maghemite (Fe2O3) intermediate. The growth and iron reduction rates of a new hyperthermophilic iron reducer, Hyperthermus strain Ro04, from the Endeavour Segment is being determined for the purpose of quantitatively modeling the growth of these organisms in situ.

By studying the physiology and physical mineral associations and transformations of hyperthermophilic iron reducers and coupling these with maintenance energy calculations, we can begin to model where these processes occur in hydrothermal systems and their impact on biogeochemical processes. Future areas of research include characterizing the nature of hyperthermophile-mineral interactions and transformations using M□ssbauer, FTIR, and nano-XANES spectroscopies along with electron microprobe and XRD. This will hopefully lead to the determination of biosignatures and the development of in situ sensors for this metabolic process.

Contributions to Integration and Synthesis:
This will contribute to the understanding of microbe-mineral interactions, the mineral transformations and how both of these affect biogeochemical processes.

Cabled Observatory Vent Imaging Sonar (COVIS) Connected to NEPTUNE Canada Cabled Observatory

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We are excited to report that working with the ROPOS group on a R/V Thomas G. Thompson cruise (12 September-9 October 2010) the COVIS team (Applied Physics Lab-University of Washington and Rutgers University) successfully connected our new Cabled Observatory Vent Imaging System (COVIS) to the NEPTUNE Canada seafloor observatory. COVIS was powered and began acoustic imaging of hydrothermal flow at the Grotto Vent cluster in the Main Endeavour Field joining the NEPTUNE Canada seafloor cabled observatory on 29 September 2010. The purpose of our experiment is to acoustically image, quantify and monitor seafloor hydrothermal flow on timescales of hours (response to ocean tides) to weeks-months-years (response to volcanic and tectonic events) to advance understanding of these interrelated processes. To achieve this, COVIS acquires acoustic data from a ~4m above the seafloor at a fixed position. A 3-degree of freedom (yaw, pitch, and roll) computer controlled, positioning system is used to point the sonar transducers providing a large coverage area at the site. Sonar data is collected at ranges of tens of meters from targets to make three types of measurements: 1) volume backscatter intensity from suspended particulate matter and temperature fluctuations in black smoker plumes which is used to reconstruct the size and shape of the buoyant portion of a plume; 2) Doppler phase shift which is used to obtain the flow rise velocity at various levels in a buoyant plume; 3) scintillation which is used to image the area of diffuse flow seeping from the seafloor.

COVIS is presently positioned to remotely acquire data to measure these flow parameters coordinated with in situ experiments at a site at the northeastern corner of Grotto (Remotely Activated Water Sampler =RAS for diffuse flow; Benthic and Resistivity Sensor = BARS in a black smoker; Temperature sensor array in biota in diffuse flow; HD video camera). COVIS is also imaging an intense plume discharging from black smokers on top of the north tower at the northwestern corner of the Grotto vent cluster. The COVIS team is working to display time series of the buoyant plume images in near real time on the NEPTUNE Canada website.

This initial phase of the work is devoted primarily to engineering. COVIS was designed and built by the Applied Physics Lab-University of Washington in partnership with Rutgers University with support from the National Science Foundation (NSF award OCE-0824612 to APL-UW; NSF award OCE-0825088 to Rutgers). The COVIS team is working to eventually display all three types of acoustic measurements in near real time accessible to the community on the NEPTUNE Canada website.

Contributions to Integration and Synthesis:

Excerpts from Project Summary for NSF Award #0825088: “This work should enable a real-time window to seafloor hydrothermal flow and its interaction with oceanic and geological processes.” “This temporal extension will enable monitoring of fluxes of hydrothermal flow and detecting linkages with external forcing processes from tidal cycles to geologic events (earthquakes, volcanic activity).”

Endeavour Integrated Studies Site: Distribution of fin whales above hydrothermal vent fields

Soule, Dax
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From 2003-2006, we deployed an eight-station seafloor seismic network along a 10-km portion of the Endeavour segment of the Juan de Fuca ridge. In addition to microearthquakes, the network recorded an extensive data set of 20-Hz fin and blue whale calls. During the first year of operation we have identified more than 100,000 fin calls. The call rates vary seasonally with highest rates from November through January and very few calls from May to August (Soule et al.,2009). Previous work at this site has detected enhanced concentrations of zooplankton throughout the water column above the hydrothermal vent fields compared to sites ≥10 km away (Burd and Thomson 1995). As part of the project to investigate the hypothesis that whales are preferentially found above the hydrothermal vent fields, we have developed an algorithm to detect and track vocalizing whales that swim near the seismic network. The tracking algorithm can successfully track whales up to 10-15 km from the seismic network with little human intervention. The statistical analysis is focused on understanding the calling patterns and how these could be correlated with known diving patterns that have been linked to feeding (Croll, Acevedo-Gutierrez et al. 2001). For each track we measure the spatial length, total elapsed time, estimated velocity, the distribution of call intervals, and the distribution of call frequencies. My poster will present the detection results from all three years of data, as well as the whale tracks and initial statistical analysis of the call patterns from the first year of data.

Burd, B. J. and R. E. Thomson (1995). "DISTRIBUTION OF ZOOPLANKTON ASSOCIATED WITH THE ENDEAVOR RIDGE HYDROTHERMAL PLUME." Journal of Plankton Research 17(5): 965-997.

Croll, D. A., A. Acevedo-Gutierrez, et al. (2001). "The diving behavior of blue and fin whales: is dive duration shorter than expected based on oxygen stores?" Comparative Biochemistry and Physiology a-Molecular & Integrative Physiology 129(4): 797-809.

Soule, Dax C., Wilcock, William S. D., Thompson, R. E. (2009) " Distribution of fin and blue whales above hydrothermal vent fields on the Juan de Fuca Ridge, N. E. Pacific Ocean" Society for Marine Mammology Poster.

Contributions to Integration and Synthesis:
As summarized in E&O WG forum: Mantle to Mammal - White Paper: Endeavour Integrated Studies Site: Distribution of fin whales above hydrothermal vent fields. Extending ridge studies beyond "mantle to microbe" to encompass "mantle to mammal." Soule describes ongoing work to test the hypothesis that whales are preferentially found above the hydrothermal vent fields. Results of this work could confirm a trophic link between the mantle and the rest of the food chain. "Establishing this link would connect a food chain that encompasses the oldest and smallest microbes on the planet with some of the largest animals to have ever lived."

Mid-Ocean Ridge Dacites

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With increasing exploration of the seafloor, it is becoming apparent that high-silica lavas are an important component of the mid-ocean ridge system. While volumetrically small compared to mid-ocean ridge basaltic lavas, andesites and dacites have erupted at several different spreading centers; including, the Juan de Fuca Ridge, Galápagos Spreading Center, and East Pacific Rise. These lavas are typically associated with ridge discontinuities and/or regions of episodic magma supply. Although the high-silica lavas have erupted at different ridges, they show remarkably similar major element trends and incompatible trace element enrichments, suggesting that similar processes control their formation. MOR dacites are geochemically characterized by 1) elevated U, Th, Zr, and Hf; 2) relatively low Nb and Ta; 3) Al2O3, K2O, Cl, H2O concentrations that are higher than expected from fractional crystallization; 4) relatively low δ18O glass values of ~5.6 compared to values ~6.9 ‰ expected from fractional crystallization. This suggests that crustal assimilation is an important process in their petrogenesis. Petrologic modeling using AFC formulations suggest that low degree partial melting and assimilation of altered basaltic crust into crystallizing magma chamber can explain the geochemical signatures of the MOR dacites. The role that this process may have in typical MOR environments and in the formation of MORB lavas, however, is the subject of continuing debate.

Contributions to Integration and Synthesis:

While the majority of lavas erupted at mid-ocean ridges are basaltic in composition, high-silica lavas have been sampled from numerous different spreading centers; including, East Pacific Rise, Galapagos Spreading Center, Juan de Fuca Ridge, and most recently at Lau Spreading Center. Many of these lavas have similar incompatible trace element patterns on mantle normalized diagrams, suggesting that similar processes control their geochemistry. This study provides a detailed examination of the petrogenesis of dacitic lavas at the 9°N EPR, which is likely applicable to the formation of high-silica lavas at other ridges.

Termination of a decadal-scale ridge-spreading event observed using a seafloor seismic network on the Endeavour Segment, Juan de Fuca Ridge

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2. University of Oregon, Department of Geological Sciences

Microearthquakes recorded on mid-ocean ridge spreading centers using seafloor ocean-bottom seismometer (OBS) networks provide valuable constraints on the mechanisms of tectonic faulting and magmatic deformation. From 2003-2006, an eight-station OBS network comprising one broadband and seven short-period seismometers was deployed along a 10-km section of the central portion of the Endeavour Segment of the Juan de Fuca Ridge. Remotely operated vehicles (ROVs) were used to deploy the sensors below the seafloor to ensure a good coupling to the ground. The ROVs also enabled us to accurately locate the instruments on the seafloor and measure sensor orientations. The short-period instruments consisted of three orthogonal Mark Products L-28B geophones that have a flat frequency response from 1 – 90 Hz that were deployed in horizontal coreholes drilled into basalts or concrete caissons that were partially buried in sediments. The broadband instrument consisted of a three-component Guralp CMG-1T sensor that has a flat frequency response from 2.8 mHz – 50 Hz and was buried with glass beads within a caisson that was excavated into the sediments.

We have developed a Matlab-based algorithm to automatically pick P- and S-wave arrival times and calculate earthquake locations. Since our network contains extensive recordings of fin whale vocalizations, the algorithm distinguishes earthquakes from whale calls based on signal frequency. We present a 38-month catalog of automatically determined hypocentral parameters for over 37,000 earthquakes recorded along the Endeavour Segment between August 2003 and October 2006. The catalog includes two substantial and complex earthquake swarms recorded in January and February 2005 that appear to mark the termination of a multi-year non-eruptive spreading event that began with another regional swarm in 1999 that was detected using the SOSUS array. The spatial distribution of epicenters and pattern of moment release observed during the smaller January swarm are consistent with magmatic extension along the southern portion of the West Valley Segment. In contrast, seismicity associated with the larger February swarm and the pressure response in regional boreholes indicates that magmatic extension was concentrated on the northern portion of the Endeavour Segment. Vent-field seismicity levels increased within 2 days of the onset of each swarm, but the spatial distribution of seismicity was different for the two swarms. The time delay is consistent with along-axis diffusion of a hydrologic pressure transient within the upper crustal aquifer. Following the swarms, daily seismic activity levels decreased ~80% compared to pre-swarm levels, while seismicity ceased almost entirely at the segment ends. We posit that the post-swarm pattern of seismicity is a result of decrease in crustal stresses.

Contributions to Integration and Synthesis:

These results provide valuable constraints on mechanisms for oceanic crustal accretion, which is particularly relevant to the integration and synthesis efforts of the Ridge2000 community. The catalog will facilitate additional research efforts, including (1) modeling earthquake occurrence rates based on the rate-and-state friction law, (2) investigating potential linkages between temporal seismic patterns and tidal triggering, and (3) relating spatial patterns of earthquake b-values to variations in upper crustal structure. Additionally, our dataset provides an opportunity for comparative seismic studies with the EPR ISS where an eruptive spreading event was recorded by a seafloor OBS network in 2005-2006.

Interaction of a hydrothermal plume with the ambient ocean as measured by acoustic scintillation and an integral model

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The vertical velocity and temperature fluctuations of a hydrothermal plume were measured using a self-contained acoustic scintillation system at 20 m above an active hydrothermal edifice (Dante) within the Main Endeavour vent field of the Endeavour segment in Sep 2007. Thirty-six days of data with 1 hr sampling interval were recovered in which tidal oscillating patterns at semi-diurnal frequency were observed for both the plume's vertical velocity and temperature fluctuations. This tidal variability is shown to be the result of the hydrothermal plume's interaction with the ambient horizontal cross flows. There is a strong northeasterly residual flow superimposed on the tidal oscillations that enhances the flood current and diminishes the ebb current and this affects the entrainment of ambient waters into the plume. An integral model taking into account the ambient stratification and variations in the horizontal cross-flow is established to show the affects of tidally varying entrainment on the plumes physical properties.

Contributions to Integration and Synthesis:
The tidal variations observed in the acoustic scintillation measurements reflect the interaction of an integrated hydrothermal plume with its ambient environment. The tidally varying entrainment shown by the integral model is of great importance to the study of the transport of ambient chemicals and biota by a hydrothermal plume.

Wordle makes “word clouds” representations that give greater prominence to words that appear more frequently in the source text. It is an instructive way to look for common threads and points of emphasis in collected works. Interestingly, the words “hydrothermal” and “data” both appear more often than “ridge’ in our white papers. http://www.wordle.net/
Image Courtesy of Ken Rubin