Ridge 2000 Mid-Atlantic Ridge 35°N to ~37.5°N Workshop

Portland, Oregon
March 27-28, 2008

Executive Summary

On March 27 and 28, 2008, the National Science Foundation Ridge 2000 (R2K) Program sponsored a workshop in Portland, OR, to bring together researchers from the US and abroad to discuss research at the MoMAR (Monitoring on the Mid-Atlantic Ridge) site between 35°N and about 37.5°N on the Mid-Atlantic Ridge south of the Azores. The original goal of the workshop was to develop an implementation plan for the establishment of a fourth Integrated Study Site (ISS) in the MoMAR area. However, based on a mid-term review of the R2K Program that concluded that, based on time and resources remaining in the program, an ISS field program comparable to those at the other three ISSs was not feasible, the goals of the workshop were redefined to:

- Identify where to focus R2K efforts at MAR 35°-37.5°N to:
  -- best inform synthesis and interpretation of (any) focus site data
  -- broaden the applicability of R2K ISS results to the global MOR system
- Identify the key scientific areas where the US efforts can best complement other InterRidge MoMAR activities.

The workshop included presentations, plenary discussions, and breakout group deliberations. Consensus was reached on the science questions to which R2K might contribute that would broaden and augment the context for understanding MOR processes in the MoMAR area. The areas of interest included multi-segment and full segment studies, as well as studies at Rainbow vent field to provide a comparison of an ultramafic-hosted vent site to the basalt- and andesite-hosted sites at the current ISSs. For each of these, specific questions and experiments were defined that the workshop participants believed would (i) inform and/or extend the synthesis and interpretation of results from the R2K ISSs, and (ii) build on, and complement, the European research activities at MoMAR. They were also designed around specific linkages in the mantle-microbe scenario: mantle-crust linkages, site-specific crust-hydrothermal-biological linkages, and regional biogeography-physical oceanography linkages.

The workshop participants also discussed other issues, including the need for a MoMAR Oversight Committee and an open data policy, and the Lucky Strike hydrothermal site as an ideal target for time-critical studies. In addition, concerns were raised over a number of issues in the program review that need to be addressed by the R2K Steering Committee. These include clarification of the likelihood of additional fieldwork at the ISSs, the extent of work likely at MoMAR given it will not be an ISS, the balance in R2K between modeling and observational studies, and positioning of R2K for a future, new program.

Introduction

On March 27 and 28, 2008, the National Science Foundation Ridge 2000 (R2K) Program sponsored a workshop in Portland, Oregon, to bring together researchers from the US and abroad to discuss research at the MoMAR (Monitoring on the Mid-Atlantic Ridge) site between 35°N and about 37.5°N on the Mid-Atlantic Ridge south of the Azores. This was the fifth in a series of US and international workshops focused on the MoMAR and directly associated projects:

InterRidge MoMAR I Workshop (Lisbon, 1998) – established the scientific basis for long-term observations and monitoring, and chose the MoMAR region as the preferred site for concentrated, long-term studies, with the Lucky Strike segment and vent field as the site for small-scale studies.

InterRidge MoMAR II Workshop (Horta, Azores, 2002) – established the technical goals and experimental plans, and better defined the geographical scope and targets.

R2K Mid-Atlantic Ridge Workshop (Providence, RI, 2004) – developed a consensus that the US would focus its Atlantic studies in the MoMAR region, and this would be proposed as the R2K Integrated Study Site on a slow spreading ridge.

InterRidge MoMAR III Workshop (Lisbon, 2005) – developed detailed scientific objectives and experiments for studies at different spatial scales – multi-segment, single segment, vent scale (with the Lucky Strike vent field as the bulls-eye for the European Union observatory and the Rainbow vent field as a comparison site) – and an implementation plan to move the studies forward.

Although work at MoMAR by European InterRidge colleagues has continued to accelerate over the last three years, there has been less progress by the US community because the R2K Program has been focusing its efforts on three Integrated Study Sites (ISS): the East Pacific Rise (EPR) at 8-11°N, the Endeavour Segment of the Juan de Fuca Ridge (JdF), and the Eastern Lau Basin Spreading Center. However, in April 2007, the R2K Steering Committee developed a plan to transition the EPR and JdF ISS studies into a phase of synthesis and integration, and to begin work on establishing a fourth ISS in the MoMAR region. The community was informed of the plan via Weekly Log and website announcements in May, and in the Summer 2007 Newsletter. The March 2008 workshop in Oregon was scheduled to develop an implementation plan for R2K work in the MoMAR region.

In late February 2008, the National Science Foundation convened a panel to conduct a mid-term review of the accomplishments and future of the Ridge 2000 Program. The panel's report, released to the community ten days before the MAR workshop, stated that:

"The panel notes that with the time and funding remaining in the program, R2K will not manage a comparable ISS field program in the Atlantic to those carried out at the other ISSs. The panel recognizes the potential rewards in studying the slow spreading Mid-Atlantic Ridge for the science, for involving a wider community and in collaborating with European scientists. In order to justify beginning any work in the Atlantic in collaboration with the Europeans, the panel considers that R2K needs first to (a) clearly

explain how this work will benefit the synthetic modeling goals of R2K as stated in the Science Plan, and (b) present an in-depth synthesis of what is known about the MAR region chosen. With the possibility of funding for only 1 or 2 more field programs in R2K, MAR work that helps complete synthesis or modeling based on the other ISS may be justifiable."

The R2K Steering Committee believes that well-targeted projects that emphasize links/interplay within the mantle to microbe system can address Program goals, and the expectation is that a few strong MAR proposals will be seriously considered for funding. However, since the scope of US work at MoMAR in the next few years will not entail a full suite of focus site and broader contextual studies, the development of a full implementation plan is no longer appropriate. Hence, the goals of the meeting were redefined as:

- Identify where to focus R2K efforts at MAR 35°-37.5°N to:
  -- best inform synthesis and interpretation of (any) focus site data
  -- broaden the applicability of R2K ISS results to the global MOR system
- Identify the key scientific areas where the US efforts can best complement other InterRidge MoMAR activities.

In addition, other important scientific questions that could be addressed in the MoMAR area, whether under the auspices of R2K or not, were also recorded.

The NSF program review raised a number of issues that the Workshop participants believe need to be addressed by the R2K Steering Committee. A clear message needs to be distributed to the community on these issues, which are detailed at the end of this report.

Workshop Overview

The workshop was held at the Hotel Monaco, Portland, OR, and was attended by 50 US participants, and 9 participants from China, France, Germany, Portugal, and the United Kingdom (see Appendix 1 for a list of participants).

The workshop included presentations, plenary discussions, and breakout group deliberations (see Appendix 2 for the agenda). The first part of Day 1 was devoted to a summary of recent work at MoMAR by the European scientific community, including cruises, samples and data acquired, instrument deployments, and sensor development. Progress also includes the MoMAR area being selected as one of the ESONET sites for a 12-month demonstration of a non-cabled, deep-sea observatory at Lucky Strike Seamount.

Based on the information presented regarding the extent of European efforts and plans, the participants were divided into four breakout groups, each of which was asked to consider two questions:

1. Given the EU work in the MoMAR region, what *specific* science questions can R2K address to complement their efforts?

2. In what ways does addressing these specific questions either inform synthesis and integration that is underway at the R2K ISSs, or broaden the applicability of ISS results to the MOR system?

The result of these deliberations was a large degree of consensus on the science questions to which R2K might contribute that would broaden and augment the context for understanding MOR processes in the MoMAR area. The areas of interest identified were:

- multi-segment scale studies: large-scale mantle flow, ridge segmentation, physical oceanography and its links to larval dispersal and biogeography
- full segment scale studies: melt focusing, along-segment crustal structure and compositional variations, distribution of hydrothermal activity and its relation to volcanism and tectonism
- Rainbow vent field studies: comparison to the basalt- and andesite-hosted sites at the current ISS, source of heat, abiotic synthesis of hydrocarbons, etc.

Having reached some consensus on the scientific questions of interest, three new groups were broken out relating to the specific linkages in the mantle-microbe scenario that those questions addressed: mantle-crust linkages, site-specific crust-hydrothermal-biological linkages, and regional biogeography-physical oceanography linkages. Each breakout group was tasked with addressing the following two questions:

1. What specific type of study would contribute to better understanding of the linkage(s) in question?
2. In what ways does addressing these specific questions either inform synthesis and integration that is underway at the R2K ISSs, or broaden the applicability of ISS results to the MOR system?

Based on the Day 1 deliberations, a set of potential experiments of interest to the US community were identified that would complement European activities:

Multi-Segment/Segment Scale Studies

1) Geophysical experiments to examine:
    1) melt supply beneath the Lucky Strike segment
    2) heat supply for peridotite-hosted system (Rainbow)

2) Sampling along rift valley walls and at segment ends to examine:
    1) segment-scale variations
    2) lower crustal composition/alteration

3) Full characterization of hydrothermal outflow along the segment to constrain:
    Energy fluxes from hydrothermal systems
    Geometry of recharge zones and heat sources

4) Quantification of chemical controls on the structure and composition of biological communities

5) Larval dispersal and biogeography.

Vent Scale Studies

6) Drilling and sampling of subsurface fluids, deep biosphere at Lucky Strike
7) Determination of the contribution of abiotic synthesis to support heterotrophic organisms
8) Verification of the relationship between theoretical models of available chemical energy and microbial activity
9) Microbial biogeography
10) Heat and chemical fluxes (potential for time series) at Rainbow
11) Fe oxidation and global biogeochemical cycling differences.

Five breakout groups were formed to discuss subsets of these experiments paying attention to the:

- types of experiments – how they inform the R2K ISS
- designs and approaches for the experiments
- technology requirements
- opportunities and strategies for collaborative/cooperative efforts
- timeline of execution.

Summary of Results

This section presents a compilation of deliberations during all the breakout sessions. Some of the sub-divisions listed above have been grouped together so that the summary is organized by the questions and types of experiments that the workshop participants believe can:

(i) inform and/or extend the synthesis and interpretation of results from the R2K ISSs

(ii) build on the large dataset already available in the MoMAR area to conduct specific experiments that either augment the considerable European efforts in the area, or address processes not included in the European effort, that will help elucidate linkages in the mantle-microbe system.

1. Multi-Segment/Segment Evaluation of Melt Generation and Focusing

Unlike the three Pacific ISSs, the Mid-Atlantic Ridge is strongly segmented. Segmentation fundamentally controls melt delivery and thermal evolution, and thus the distribution and longevity of hydrothermal systems. We have decades of models for the segmentation at ocean ridges and the nature of mantle flow and melt migration, but we do not have the data set to address the questions of 2D and 3D flow. The MoMAR area is also distinct in that it is proximal to the Azores hotspot, which may influence patterns of mantle melting and flow beneath the MOR. This multi-segment perspective is not being fully addressed by the European MoMAR effort.

Another important question concerns the nature of the heat source driving the Rainbow hydrothermal system. There is insufficient heat from serpentinization reactions (which are exothermic) to drive a high-temperature system; hence, there must be a source of heat (either molten or hot, solid rock) at depth.

Scientific Questions

- Why is the MAR segmented and how does segmentation influence regional melting and mantle flow in the MoMAR area?
- What is the influence of the Azores hotspot on mantle flow, melt production and melt migration in the MoMAR area?
- What is the nature and location of the heat source driving the ultramafic-hosted hydrothermal system?

Experiments

A multi-segment program of geophysical studies is needed that builds on the results of SISMOMAR. Multi-segment geophysical studies would start to investigate melt generation in the mantle and its relation to segmentation, and mantle flow related to hotspot influence. Such studies are important in linking crustal structure and hydrothermal systems to the distribution of melt and melt focusing.

Within the larger context of understanding melt generation and flow along mid-ocean ridges, a series of overlapping and nested passive and active source seismic experiments is required in the following areas:

(i) the highly segmented ridge segment south of, and including, the Oceanographer Fracture Zone (FZ)
(ii) along the MoMAR region of the MAR
(iii) the Azores platform and north of Azores.

Understanding melt generation in the mantle and its relation to ridge segmentation has been a goal of the ridge scientific community for ~20 years. Hence, the highest priority for the mantle community is the segmented region south of Oceanographer FZ. This region is characterized by segments of differing length, gravity anomaly, morphology and offset size. The Oceanographer FZ is the first large-offset fracture zone south of the Azores triple junction and should be included in any investigation into the fundamental nature of ridge segmentation at a slow-spreading ridge. The crustal structure of the three segments south of the Oceanographer FZ is also well characterized. However, this area is too far from the Lucky Strike segment for a single experiment that both integrates with focused studies at the Lucky Strike segment, and addresses the relationship of segmented crustal structure to mantle flow, melt production and melt migration to be feasible.

The MoMAR region is a transitional, hot-spot influenced region with depths decreasing northward and relatively small, non-transform offsets of the spreading center. This is an ideal section to study the influence of the Azores hotspot and to complete the mantle to microbe linkage at the Rainbow and Lucky Strike hydrothermal sites. In the MoMAR region, only the Lucky Strike segment has been studied with modern tomographic techniques; thus, an active seismic experiment is necessary to characterize the crustal structure of other segments in this region. This experiment would link crustal structure and hydrothermal systems to the distribution of melt and melt focusing.

North of the triple junction, the ridge is unsegmented and orthogonal to the direction of spreading providing a setting that contrasts with the other two regions. Thus ultimately, a series of three experiments extending from south of Oceanographer to north of the triple junction could fully address the questions of ridge segmentation and mantle flow.

Given the logistical and financial realities of the R2K Program, it is probably not feasible that these three experiments can be done within the Program. However, it should be possible to include a SISMOMAR-like, active source experiment to characterize structure (melt, crustal production, faulting) beneath the Rainbow hydrothermal field. Such an experiment would require a cruise of the *Langseth* in the Atlantic and a number of short-period OBSs available for a short time. Each of the passive experiments described would require 50-70 broadband OBSs available for 15 to 18 months. Given the lead time required to schedule broadband instruments, under the most optimistic scenario, data from a passive experiment could not begin to be analyzed until the end of R2K.

2. Segment-Scale Variations in the Chemistry of Upper and Lower Crustal Rocks and Their Hydrothermal Alteration

The MAR at 35-37.5°N provides the best opportunity to investigate what is happening in the subsurface for any of the R2K ISSs. Lower crustal rocks have not been sampled in the R2K ISSs, and upper crustal rocks have not been well sampled at the segment ends. Hence, the variation in chemical composition of the oceanic crust along segments is not well known. There has been no rock sampling up the rift valley walls anywhere in the Lucky Strike segment. Recovery of gabbro and ultramafic rocks would have important implications for understanding magmatic processes beneath the segment and correlating it with the distribution of lavas sampled across the center of the segment.

In addition, it is likely that the chemistry of hydrothermal fluids is determined by water-rock reactions in the lower crust. Therefore, sampling along segments is important to understand both segment-scale variations and alteration of the lower crust.

Questions

- How does the geochemistry of the crust change along the Lucky Strike segment, and how is it influenced by proximity to the Azores hotspot?
- What can the composition of exposed lower crust and mantle rocks reveal about magmatic processes beneath slow spreading ridges?
- What water-rock reactions occur in the lower crust/mantle and how do they influence hydrothermal fluid chemistry?

Experiments

Interpretation of the crustal structure and hydrothermal systems at the ISSs has benefited from an understanding of the geochemical context of the volcanic rocks in those areas. Similarly, studies of eruptive rocks in the Lucky Strike segment can provide this context. However, basalt sampling is very sparse at the ends of the Lucky Strike segment. Thus, there should be a modest program of along-axis basalt sampling at the segment ends of the Lucky Strike segment. An economic sampling program using dredges and wax coring could be completed using existing bathymetric maps and would require only a few days of ship time. In addition, a program of dredging up the rift valley walls to sample gabbro and ultramafic rocks would also be important for constraining the crustal structure along slow spreading ridges, and the influence of the Azores hot spot on crustal thickness, structure and composition.

The Rainbow hydrothermal field is hosted in ultramafic rocks, and hence is distinct from hydrothermal systems sampled in the R2K ISSs. While experimentalists attempt to recreate water-rock reactions in this zone, it is important to obtain natural samples of the reaction and upflow zones.

The optimal program would be to obtain a full suite of rocks from the reaction zone directly supplying fluids to the Rainbow hydrothermal field. This may be possible by drilling with a rock drill along the detachment surface in the area. The risk of this approach is that the drill may not have sufficient capabilities, and/or that the reaction and deep upflow zones may not be exposed near enough to the surface.

A lower risk experiment would be to identify, map, and sample the core complex that is likely present in the adjacent segment north of Oceanographer Fracture Zone. There is a better chance of recovering the diverse rock types and hydrothermally altered rocks that must underlie the hydrothermal systems. The drawback of this experiment is that the core complex is not in the same segment as the Rainbow hydrothermal field. Mapping (surface bathymetry, gravity, magnetics) and dredging such a core complex, however, would document the architecture of the lower crust and shallow mantle underlying magmatic segments in this region of the MAR. Moreover, the Rainbow hydrothermal site is thought to overlie a detachment fault like those exposing the oceanic core complexes flanking the Oceanographer F.Z. Thus, such a program would directly sample the fluid transport and reaction zones for hydrothermal systems analogous to the Rainbow site.

While it may be preferable to do all this on the very segment on which Rainbow occurs, it is highly unlikely that the lower crustal architecture and the nature of the detachment faulting there differs significantly from that at the segment immediately to the south. Moreover, there is no more guarantee that conditions were any different during exposure of the core complexes, than that they were any different for the rocks now exposed on the rift valley walls of the Rainbow segment. In fact, a comprehensive dredging program on a large core complex, will likely yield rocks produced at different stages of hydro-magmatic activity, and thus is more likely to recover materials appropriate to the source region and upflow zone for Rainbow, than simply dredging the adjacent rift valley walls which will likely only recover a few bits of sheared serpentinite.

There is ample opportunity to collaborate with European colleagues, some of whom are leaders in the study of alteration of ultramafic rocks. Collaboration could be through field studies as well as analytical studies. There are no difficult technical requirements to overcome, except perhaps the capabilities of the German rock drill.

3. Along-Segment Hydrothermal Vent Characterization

The complete spatial distribution of hydrothermal venting, both low temperature and high temperature, along the Lucky Strike segment is important for constraining the segment-scale flux of heat and the distribution of hydrothermal vent sites. Since 1991, there have been indications that there are a number of sites of venting present throughout the segment. Despite this, and although the Lucky Strike vent field at the seamount summit has been studied for 15 years, only in the last 2 years has another vent site on the southern flank of the seamount (Ewan) been found.

Recent numerical models for slow-spreading mid-ocean ridges (MORs) predict the existence of short-lived vent sites away from the segment center. Finding new vent sites is essential for testing and calibrating the existing models for hydrothermal circulation at slow-spreading MORs. Understanding the association of venting with either tectonic or volcanic features is important in deciphering the controls on permeability structure at different depths, and will help elucidate the geometry of hydrothermal convection cells.

A characterization of the total hydrothermal output and distribution of vents at Lucky Strike would permit comparison with both the EPR and Endeavour ISSs where the ridge and underlying magma lenses have a more 2-dimensional structure. The addition of data from a 3-dimensional system would provide further constraints on both conceptual and numerical models of hydrothermal systems at the R2K ISS, and on the energy flow from the mantle to the hydrosphere.

Questions

- What is the energy flux associated with hydrothermal activity for the Lucky Strike segment?
- What is the relation between volcanic and tectonic features and hydrothermal activity along the Lucky Strike segment?
- How do these relations influence the geometry of hydrothermal convection cells?

Experiments

A multidisciplinary program of CTD tow-yos and water-column surveys along and across the segment, from end to end, would define the current state of the hydrothermal system(s) along the segment. During the same cruise, strategic deployment of AUV(s) over areas influenced by hydrothermal plumes could refine the location of the buoyant plume at each site, and the location of seafloor vent sites throughout the segment. During AUV dives, a program of sediment gravity coring across axis throughout the segment would help define the time-integrated nature of venting through the segment. In addition, a towed camera system deployed during AUV dives could help ground truth AUV near-bottom results and identify vent sites. It is envisioned that this type of fieldwork could be accomplished within a ~ 4-5 week cruise, and that such a cruise should be conducted early on at the Lucky Strike segment.

4. Chemical Controls on the Structure and Composition of Biological Communities

Integrated biological and chemical studies at the MoMAR site will expand the global perspective of mantle to microbe dynamics at oceanic spreading centers because of the range of vent fluid compositions that are not encountered at the three established ISSs. In particular, serpentinization reactions at the ultramafic-hosted Rainbow vent field result in some of the most highly enriched concentrations of H_2, CH_4, and Fe that have been found in high temperature vent fluids to date, while fluid-rock reactions at the basalt-hosted Lucky Strike system produce relatively oxidizing vent fluids that in some cases are extremely H_2-poor relative to other systems. Large variations in the abundance of these and other redox active species that support chemosynthetic life create an ideal natural laboratory to assess the relationship between fluid-rock reactions taking place in deep-seated reaction zones and the establishment of biological communities at and below the seafloor. Moreover, the ultramafic substrate at Rainbow provides a contrasting environment to the basaltic and andesitic substrates at the ISSs, allowing investigation of physical constraints on the colonization of vent environments by macrofauna. It is important to note that there are distinct macrobiological communities at Lucky Strike (mussel-dominated) and Rainbow (shrimp-dominated) that would provide additional perspectives on the relationship between the substrate and the geographic distribution of organisms.

The Rainbow hydrothermal field also provides an excellent opportunity to test the possibility that abiotically synthesized organic compounds are capable of supporting microorganisms. While we know that autotrophs (e.g. methanogens) are supported by water-mantle reactions, heterotrophy utilizing abiotic organic compounds would be new. Organic compounds with an apparent abiotic origin are present in Rainbow hydrothermal fluids at relatively high concentrations suggesting an important linkage between hydrothermal processes occurring in mantle rocks and the maintenance of seafloor vent communities.

Questions

- Are there significant differences in the microbial diversity, abundance of certain physiological groups (e.g. hydrogen oxidizers, methanogens and iron oxidizers/reducers) that may reflect the fluid chemistry and substrate differences?
- What are the physical or chemical constraints that control the distinct macrobiological distributions between Lucky Strike and Rainbow? Does this help explain the distinct macrobiological distributions seen, for example, at Rainbow and the current R2K ISSs?
- Do differences in substrate and fluid chemistry influence microbial biogeography?
- What is the contribution of abiotic synthesis to the organic composition of hydrothermal fluids at the Rainbow hydrothermal field, and do these compounds support heterotrophic organisms?
- Is primary colonization of vent deposits different from other hydrothermal sites due to the availability of alternative carbon sources? Are there significant differences between the extent of carbon fixation at the ultramafic-hosted Rainbow site and the basalt-hosted sites present elsewhere?

- Given the differences in the chemistry between the different R2K ISS sites and MoMAR, can we use theoretical chemical models of available energy to predict prevalent microbial activities and diversity? Can these models be used to direct novel approaches to growing some of the as yet uncultured microorganisms from deep-sea vents?

Experiments

Using a combination of culture-dependent and -independent approaches, the patterns of microbial diversity can be compared across sites. Statistical tools can be used to determine which physical and chemical parameters might explain the observed patterns. Functional genes can also be used to explore the abundance and distribution of different microbial physiologies in response to differences in fluid chemistries.

Characterization of the composition and abundance of organic compounds at the Rainbow vent site could help define media compositions for isolating novel deep-sea vent heterotrophs. The diversity and physiology of these heterotrophs could be compared with heterotrophs from the R2K ISSs to explore possible ecophysiological differences that can be attributed to organic geochemical differences between vent sites.

The hydrothermally-cemented breccia at the Lucky Strike vent field, through which diffuse fluids are venting, likely provides a zone of mixing between vent fluids and seawater beneath the seafloor that could support a subseafloor microbial community. Shallow drilling through the cemented breccia could provide an opportunity to directly sample the subsurface biosphere – something that cannot be easily done at the three ISSs. Such a drill hole would allow chemical characterization of the subsurface environment through collection of fluids ponded beneath the surface, and would provide a mechanism to deploy *in situ* chemical/physical sensors and conduct *in situ* incubation experiments. If successful, this would be the first sampling of the subsurface biosphere on a MOR system and would provide a constraint for models being developed at R2K ISSs.

The composition of fluids and rocks collected at the MAR could be used as input constraints on theoretical thermodynamic models that estimate the amount of chemical energy available from metabolically-relevant chemical reactions. Such calculations represent a powerful means to assess the viability of metabolic strategies and microbial diversity in vent environments, and to place constraints on the contribution of mid-ocean ridge hydrothermal systems to carbon fixation and elemental cycling in the deep sea.

5. Larval Dispersal and Biogeography

At MoMAR, the geologic settings of Rainbow and Lucky Strike vent fields within the bounding topography of the MAR rift valley, together with prevailing along-axis, deep-sea currents that flow from south to north, offer an exciting potential for detailed investigation of along-axis migration between vent sites. This has been given further fresh impetus by new evidence that confirms the presence of additional sites of venting within the rift-valley, between Lucky Strike and Rainbow. The EPR ISS hydrothermal plumes are not constrained topographically whereas, in contrast, deep flow along the MAR rift valley may place greater restrictions on larval dispersal, hence influencing biogeography.

Questions

- How does restricted, one-dimensional flow of bottom water change the model currently under development at the EPR ISS for dispersal of balloonists and demersal larvae?
- Is the uni-directional flow along the MAR rift valley continuous between Rainbow and Lucky Strike?
- What is the genetic connectivity between vent communities along the MoMAR segments?

Experiments

Experiments similar to the LADDER experiment conducted at the EPR ISS that involve larval dispersal studies in conjunction with moorings and sediment traps would be an important contribution, and would allow for direct comparison of MoMAR larval dispersal with that modeled at the EPR ISS. In addition, it might be possible to modify camera systems, designed for use in coastal areas to detect larvae, for use at vent sites.

A particularly important contribution would be to instrument the rift valley for along-axis flow, not only at Rainbow and at Lucky Strike, but also at other key sites between adjacent 2nd order ridge segments, to determine the along-axis continuity of deep-water flow between vents. For example, the non-buoyant plume from Rainbow is already known from *in situ* sensors and water column analyses to stretch as far as the southern end of the FAMOUS segment, while new evidence has confirmed the presence of a further high-temperature hydrothermal source at the southern end of the Lucky Strike segment. At a minimum, physical oceanographic instrumentation (± sensors and samplers for larval dispersion/ biogeochemical fluxes) would prove extremely valuable at these sites.

6. Heat and Chemical Fluxes at the Rainbow Hydrothermal Field

At the Rainbow hydrothermal vent field, the non-buoyant hydrothermal plume is constrained by the bounding topography of the MAR rift valley, and is dispersed in a predictable manner by prevailing along-axis currents flowing from south to north at speeds on the order of 10 cm/sec. This makes the Rainbow site particularly amenable to examination of export fluxes of heat and chemicals to the surrounding ocean.

A complication arises, however, in that the Rainbow plume is unusually Fe-rich. This is the result of the high Fe:H_2S ratio in the vent fluids; this led to the suggestion that chemosynthesis at Rainbow may be dominated by Fe-oxidizing ± H_2-oxidizing microbes. Hence, microbial Fe oxidizers may play an important role at Rainbow, although in this plume, the rate of *inorganic* Fe oxidation will be significantly faster than at any of the R2K ISS sites in the less oxidizing Pacific Ocean.

What is also particularly unusual about Rainbow is that it is an apparently long-lived high temperature field hosted in ultramafic rocks. This suggests that, in addition to serpentinization, there must be some additional heat source that drives hydrothermal circulation. This heat source must be substantial but, at present, remains unknown.

Questions

- What implications does a topographically constrained hydrothermal plume have for export of heat and chemicals? Can we establish a time-series?
- Are the controls of the fate of Fe in the hydrothermal plume due to microbial activity or abiotic reactions?
- What is the heat source at Rainbow, and how can the heat flux observed at Rainbow be sustained over the time scales inferred from sediment records?

Experiments

The most valuable experiment that could be performed at Rainbow would be the deployment of a state-of-the-art LADDER-type array to provide a direct comparison with the EPR ISS and investigate differences between fluxes from relatively short-lived (decades?) hydrothermal systems fueled by a basaltic volcano-magmatic system and those from a tectonically-controlled, ultramafic-hosted system. Preliminary work in the 1990s using a much cruder instrument array provided a first-order synthesis of heat and chemical export fluxes. However, these could be far better constrained with a repeat study that would provide an opportunity for time-series both within the new study (e.g., over a 12 month deployment) and between this work and the earlier 1990s investigations.

Following the hypothesis that Fe-oxidation rates in hydrothermal plumes might vary along the thermohaline conveyor (based on work at the EPR ISS), experiments conducted at the Central Indian Ridge have suggested that there are, indeed, systematic variations in Fe-oxidation in different ocean basins. However, such work has not yet been performed at any MAR vent site. An obvious experiment at the Fe-rich Rainbow hydrothermal field would be to conduct *in situ* and shipboard incubation experiments (poisoned or unpoisoned) to investigate both rates of Fe-oxidation and the potential role of microbial activity in catalyzing, and gaining energy from, these reactions.

Once export fluxes of heat have been better constrained, new geophysical experiments can be better designed (see Section 1 above) to further investigate the nature of the heat source at the Rainbow hydrothermal vent field.

Other Issues

MoMAR Oversight Committee

The need for mechanisms to foster collaboration/cooperation among all InterRidge investigators, currently US and European, as well as coordination of activities particularly at the focus sites (Lucky Strike seamount and Rainbow hydrothermal field), was discussed. There is currently an InterRidge Monitoring and Observatories Working Group, chaired by Javier Escartin, which has a focus on the MoMAR area. Its mandate has not yet been established, but the workshop would like to recommend that some of the tasks of the Working Group include:

1. Facilitate science planning, and stimulate coordinated, interdisciplinary research through, for example, communications about the science that individuals are interested in doing in the MoMAR area. There is a MoMAR website managed by

Javier Escartin (http://www.ipgp.jussieu.fr/rech/lgm/MOMAR/) that needs to be updated and kept current.

2. Oversee coordination of ship scheduling and scientific activities as well as helping with logistics and permitting in the MoMAR area
3. Develop a data policy that ensures data are widely available.

Data Collection and Data Policy

In order to conduct synthesis and integration activities, data need to be made available as soon as possible. While R2K has a policy of open and available metadata immediately following field programs, and full data availability within 2 years, such a system may not be acceptable to European colleagues. A first step would be to ensure that metadata are widely available so that individual investigators can make contact with those holding data relevant to a particular project. However, it is important that basic datasets, such as multibeam bathymetry, be made available to those planning expeditions in the MoMAR area. The French host a national databank at IFREMER called SISMER (http://www.ifremer.fr/sismer); data can be requested from this site.

Time-Critical Studies

The planned pilot ESONET observatory at the Lucky Strike vent fields, as well as the proximity to the Azores, makes this an ideal target for time-critical studies. The ESONET buoy will send snippets of seismic and temperature data by satellite telemetry from the vent fields. If the situation arises, R2K should be able to assist in launching a rapid response effort. The presence of a small 6-berth research vessel in the Azores is an ideal platform for a CTD/ tow-cam program that could be deployed very rapidly.

Program Review Concerns

The NSF mid-term program review has raised a number of issues that the Workshop participants believe need to be addressed by the R2K Steering Committee and a clear message needs to be distributed to the community on the following issues:

- ***Fieldwork at the ISSs***: The R2K Steering Committee informed the community in December 2007 that field work at the EPR and JdF ISS would no longer be funded through R2K. However, the program review was less restrictive, stating that integration, synthesis and modeling “should take precedence over, and provide justification for, any new field studies”. Workshop participants commented that there might be a need for collection of additional datasets at the ISSs in order to bring closure to one or more linkages in the mantle-microbe system. Hence, the situation regarding fieldwork at the ISSs needs to be clarified.
- ***Extent of work at the Mid-Atlantic Ridge***: Given that MoMAR will not be an R2K ISS in terms of the scope of work to be accomplished there, the Steering Committee needs to provide guidance to the community regarding the extent of work that can be conducted, either to inform/expand interpretation of data from the ISSs, or to provide additional components to the European efforts.
- ***Balance between modeling and observational activities:*** With the recommendation

from the review panel, endorsed by NSF, that integration, synthesis and modeling should become the highest priority during the remaining years of R2K, the Steering Committee needs to consider the balance between modeling and observational activities over the next few years.

- ***Positioning R2K for a future, new program:*** While R2K will end in 2012, the results from the program will hopefully lead to a new and exciting program of mid-ocean ridge research of some sort. What the focus of that effort will be remains unclear. However, the Steering Committee needs to view the next 4 years not only as bringing closure to R2K, but also to providing a legacy that will provide justification for a new, exciting program of research.

APPENDICES

Appendix 1: List of Attendees

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Appendix 2: Agenda

MID-ATLANTIC RIDGE ~35-37.5°N INTEGRATED STUDIES SITE
RIDGE 2000 WORKSHOP, PORTLAND OREGON

THURSDAY, MARCH 27

8:30 Overview of R2K opportunities at a Mid-Atlantic Ridge ~35°-37.5°N ISS
Susan Humphris

9:00 Review of InterRidge work at MoMAR
Overview of Recent Investigations, Javier Escartin
ESONET and Azores partnerships, *Ana Colaco, Pierre Marie Sarradin*

10:30 First Breakout Groups
Four interdisciplinary groups are tasked to discuss R2K-specific opportunities that MoMAR region present

LUNCH 12:15

13:30 Plenary Discussion of results of First Breakout Groups.

15:30 2nd Breakout groups
Three groups focused, around the following: mantle-crust linkages, site-specific crust-hydrothermal-biological linkages, and regional biogeography-physical oceanography linkages, are tasked with addressing R2K-specific and broader InterRidge efforts.

16:30 Plenary brief reports on Second Breakout Group discussions

FRIDAY, MARCH 28

8:30 Plenary Brief review of prior day outcomes; scope of R2K work within 35-37.5°N area (group discussion).

9:30 Third Breakout Groups
Steps for implementing work at various scales (multi-segment, single-segment, given hydrothermal field(s), given vent(s) or habitat) inter-disciplinary groups

11:15 Plenary reports from Third Breakout Group discussions

LUNCH 12:15