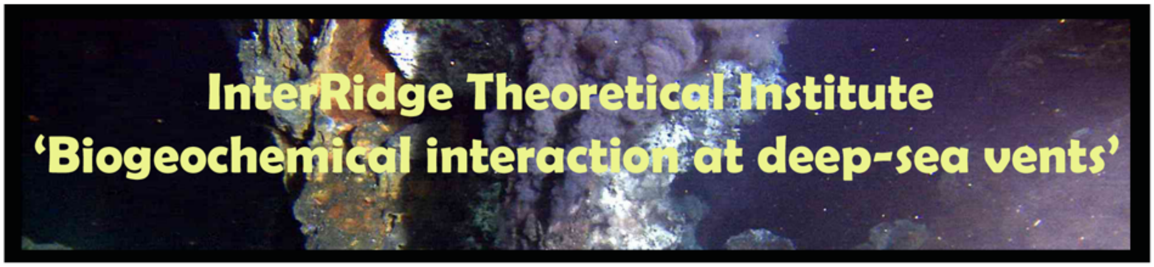

Woods Hole, USA, Sept. 10-14, 2007

IRTI scientific committee and working group chairs: N. Le Bris, M. K. Tivey, C. R. German, S. M. Sievert, K. Takai, F. Gaill, J. Lin, W. Bach, K. Edwards, P.-M. Sarradin, J. Holden, D. Connelly, M. Lilley

1. Introduction

The ***Biogeochemical interaction at deep-sea vents*** **Working Group** held the third InterRidge Theoretical Institute at Woods Hole Oceanographic Institution in Woods Hole, MA, USA, from September 10-14, 2007. The goal of the institute was to foster multidisciplinary research on the interactions between the biological and chemical components of deep-sea environments associated with hydrothermal circulation--particularly the biogeochemical processes driving these interactions. The event was co-sponsored by InterRidge, Ridge 2000 (USA), JAMSTEC (Japan), IFREMER (France), CNRS (France), and WHOI's Deep Ocean Exploration Institute (USA).

The Theoretical Institute featured two days of lectures, a poster session, and a three-day workshop. The first two days included introductory talks focusing on the key issues requiring interdisciplinary approaches. The final days featured five working groups that enabled scientists to discuss in detail the development of relevant strategies and collaborative projects.

More than 127 scientists attended the lectures, and roughly 80 participants attended the working group discussions. Students and post-docs were particularly well represented. Of the 47 poster presentations, most were given by students. Jillian (Petersen) Struck from the Max Planck Institute for Marine Microbiology in Bremen, Germany, won the **IR outstanding student poster award** for her poster entitled 'Hydrogen is an energy source for endosymbiotic bacteria of hydrothermal vent mussels'. Short "flash" communications by Ph.D. students and post-docs completed the presentation of on-going researches in the field.

2. Advanced workshop lectures: The "international school"

In the initial lectures, experts summarized the current collective understanding of the links between key geological, physical, chemical, and biological processes at vents including the processes driving the variability of environmental conditions associated with hydrothermal venting, the thermodynamic and physiological constraints on energy transfer from chemical to biological systems, and their role in vent ecosystem dynamics.

It was first emphasized that the diversity of end-member chemical composition is likely to be unlimited—reflecting complex interactions between rocks and seawater, and phase separation processes at high temperature and pressure. Transport and mixing pathways below and above the seafloor, as well as biological activity itself, further generate chemical variability and create a mosaic of microenvironments with highly diverse physico-chemical properties. The wide diversity of microbial communities and the variety of chemosynthetic energy pathways they rely on, provide another layer to this environmental diversity. The question of whether 'chemistry drives biological diversity' or 'biology drives chemical conditions' remains a matter of debate. A concluding message to the lectures was that the interaction of processes that define the molecular architecture of these biogeochemical systems is more complex than previously thought. At the scale of whole communities and ecosystems, biological interactions and physical processes should still play a major role in regulating these fundamental biogeochemical interactions in space and time.

This "international school" established that a better understanding of the reciprocal influences between the abiotic and biotic components of the systems is needed—not only to improve the understanding of biogeochemical processes and their role in the ecosystems, but also to investigate how biological systems may serve as indicators of geophysical and geological processes taking place beneath the seafloor. Proposed strategies to achieve these goals included: developing *in situ* and *in vivo* approaches to characterize the diversity, modelling from which hypotheses can be formulated, and experiments to test these hypotheses. Examples of the advances made thanks to the following novel techniques and approaches were presented: *in situ* electrochemical sensing of chemical speciation, combined cultivation approaches and molecular biology techniques for microbial diversity and gene expression studies, and integrated multidisciplinary *in situ* experiments.

3. Working Group discussions

The aim of the workshop was to focus on some key issues that will drive vent research in the near future. Five Working Group (WG) topics were chosen as focus topics that would benefit from international cooperation:

- Regional-scale plume studies and water column chemistry/biogeochemistry
- The hidden biosphere: Metabolic diversity, element fluxes and mineral signatures
- Life in extreme environments: strategies and adaptations
- Observatories: tools and strategies for long-term seafloor ecosystems studies
- New approaches and tools for biological and chemical sensing.

3.1. Regional-scale plume studies and water column chemistry/biogeochemistry (WG1)

3.1.1.) Introduction

The focus of this working group was to consider the large-scale impact of hydrothermal venting on global-scale ocean biogeochemistry, and decide how best to address the topic. One particular consideration concerned whether and how the interests of InterRidge and its sister SCOR-endorsed program GEOTRACES might be melded together to achieve a common set of goals.

Consequently, the discussions followed three themes:

- A consideration of what had already been discussed by GEOTRACES, both in their recently published scientific mission statement and at their Pacific Ocean planning workshop held in Hawaii in June 2007;
- A discussion of what InterRidge biogeochemists would recommend as an *ideal suite* of observations of distributions and fluxes in a large-scale hydrothermal plume study;
- A discussion of how water-column processes and fluxes could be coordinated with seafloor observations at one or more sites of hydrothermal venting.

3.1.2.) Choice of study site

There is widespread international agreement that the large-scale (>1000km) hydrothermal plume discharging from the southern East Pacific Rise near 15°S (as identified from ^3He more than 30 years ago, and now well constrained by various programs including WOCE) would make an excellent target for investigating large-scale plume biogeochemistry. Not only is the plume large, but also:

- it is already well constrained geographically (i.e., there is enough pre-existing data to select a section of stations to conduct the optimal along-plume section + across-strike sections).
- it is coincident with the fastest-spreading section of the global ridge-crest, where the greatest flux from hydrothermal venting to the ocean would be predicted to occur.
- it overlies metal-rich sediment patterns that indicate the same flow trajectory has been established for periods that are long compared to thermohaline circulation.

This gives us confidence that this is a suitable location at which to invest significant international resources and to conduct a single large-scale process study that would be as representative as possible of the global-scale impact of hydrothermal venting on ocean biogeochemistry.

3.1.3.) Scope of Study

To address the impact of hydrothermal venting on the oceans, we identified three kinds of measurements that would be required:

i) Distributions of conservative tracers, metals, gases, nutrients, microbiology and suspended particulate matter would all be important to measure for InterRidge objectives. Conservative tracers would include conductivity, temperature and $^3He/^4He$ ratios. Measurements of metals (including their stable isotopes) would be especially important for those known to be related to enzymes and would include Fe, Mn, Al, Cu, Zn, Cd, Co, Ni, Mo, V, As, Pb & Os. To constrain distributions of dissolved gases the highest priorities would be CH_4, H_2 and CO_2 (including ^{13}C and ^{14}C isotope studies), O_2, pH and alkalinity. Nutrient studies would involve measurements of: DOC; DON, amino acids and nitrogen species (including ^{15}N investigations); sulfur species; phosphate, Si and Ge; particulate C, H, N; ATP. For microbiological studies it was recommended that our InterRidge/GEOTRACES study aim to adopt emerging collection procedures that are being implemented by IODP to serve international multi-PI needs. Work-up of these samples would include cell count studies, microscopy (including electron and fluorescent techniques) and DNA work. The final category of measurements recommended would be those related to suspended particles and this would include measuring distributions of suspended particulate matter itself (SPM), its mineralogy (e.g. through thin-film XRF, spectroscopy) and also its impact on "scavenged" tracers – notably Th, Pa, REE, Be.

ii) Biogeochemical dynamics and rates - particularly those associated with carbon fixation and respiration and nitrogen cycling. For C-fixation, uptake experiments using labeled ^{14}C and/or ^{13}C are envisaged. Thymidine incorporation could also be used (as already applied in upper-ocean studies) and fertilization experiments could be considered for all of: Fe, Mn, Zn, H_2, CH_4, S, N-species. N-cycling investigations would aim to address fixation, nitrification, ammanox, denitrification + labeling experiments.

iii) Input/output fluxes & timescales – Key considerations here would be to determine: end-member vent-fluid concentrations and fluxes from buoyant plumes (which will only be possible through access to deep-submergence assets); along- and across-plume fluxes; vertical fluxes into/out of plumes.

For fluxes through the plume we can use any pre-existing ARGOS float data coupled with predictive modelling deduced from published data on plume fall-out (metal) distributions in underlying sediments. This could be augmented, in the field, by deploying a lowered ADCP on all CTD casts and through purposeful release of additional ARGOS floats. Logistically, it might also be possible to deploy long-term moorings on/near axis at the end of a section-based cruise which could then be recovered during a follow-on submersible-based cruise.

In addition to physical flux measurements, chemical techniques might also be applicable, e.g., using $^{222}Rn/^{3}He$ fractionation, dye/SF_6 release. A major challenge for the program would be to find new ways to constrain vertical fluxes *without* reliance upon sediment traps. Technological needs here would include an *in situ* particle size *and density* analyzer. For vertical export fluxes we could also use methods already established for upper-ocean studies (e.g. based on ^{234}Th) and collection of core-top sediments to establish long-term averages. Note that, as part of a GEOTRACES-based study, any section along and across the southern EPR hydrothermal plume would also include upper ocean and full water column investigations of aeolian inputs and upper-ocean biogeochemical export fluxes.

3.1.4.) Implementation Strategy

It is clear that to implement the full scope of what is envisaged will require more than one single research cruise, no matter how elaborate that cruise might be. Rather, what will be required will be a combination of a large-scale basin-wide ***section*** (as already envisaged by GEOTRACES) coupled with a submersible-enabled ***process***-oriented study to vent sites at the ridge-axis. An obvious way forward, therefore, would be for InterRidge to continue to work together with GEOTRACES in developing this project:

- GEOTRACES should take lead responsibility for developing the **section**-based study - to ensure complementarity with all other global-scale section studies.
- InterRidge should take responsibility for *i)* developing the **process**-based study that would provide first-time users from the GEOTRACES community access to the seafloor via submersibles and *ii)* identifying which complementary studies might be accommodated on the **section**-based investigation, *in addition to* what is already envisaged as core measurements for GEOTRACES.

3.2. The hidden biosphere: Metabolic diversity, element fluxes and mineral signatures (WG2)

The aim of this session was to discuss the development of collaborations between geologists and biologists in future hydrothermal vent-related Integrated Ocean Drilling Program (IODP) proposals and exploration programs.

Hydrothermal vent systems are obvious targets for biogeochemical research, especially given the potential geochemical energy for primary production. Diffuse mixing zones in the subseafloor, where water-rock reactions supply reduced chemical species, are habitats in which a significant proportion of the microbial production within vent systems may take place. At lower temperature recharge zones and in off-axis ridge flanks, water-rock redox reactions are chemically inhibited, and may be catalyzed by microbial communities for primary production. Yet, microbial diversity and abundance, as well as feedbacks between microbial activities and processes such as mineral precipitation and dissolution in the subseafloor hydrothermal environments, are largely unexplored. Furthermore, examinations of the limits of life (as far as P, T, toxic metal concentrations are concerned) and the antiquity of the deep biosphere will help in filling gaps in the tree of life and discovering novel genetic and biochemical information.

The unique ability of IODP to access the deep subseafloor is contrasted by a lack of proposals with a focus on subseafloor life associated with hydrothermal vent activities. Microbiologists and geochemists need to develop ideas, strategies, and procedures for investigating these environments. Although it is challenging to sample the high-temperature and/or rock-hosted biosphere by drilling, obvious advantages are the ability to instrument boreholes for investigating fluid flow and fluid chemistry and use them as natural laboratories for incubation studies.

The likelihood of successful investigations of the deep biosphere at vents by ocean drilling can be maximized if a number of prerequisites are met. Firstly, potential drill sites should feature extensive diffuse venting indicative of subseafloor fluid mixing. These areas should be comprehensively investigated by seafloor sampling and observation, including fluid sampling (both discrete and diffuse), geological and biological mapping, heat flow measurements, and near-seafloor high resolution bathymetric, sonar, and magnetic surveys. Apart from subseafloor mixing zones, areas of seawater-peridotite interaction and resulting high hydrogen levels in the system were deemed particularly interesting (e.g., Rainbow, Logatchev and potentially Kairei).

Regardless of the type of setting, results from detailed seafloor surveys and data analyses should be used to develop working hypotheses of subseafloor conditions and processes of fluid mixing and heating/cooling. Shallow drilling, using ROV-mounted drills and rock drill units developed by the British Geological Survey, the German Research Center Ocean Margins or the Japan Oil, Gas and Metals National Corporation (JOGMEG), should be used to sample the uppermost meters to decameters of basement. These shallowest parts of the system are difficult to core by IODP drilling, which therefore needs to be coupled with other seafloor drilling platforms in order to maximize coverage. Here we may take advantage of the new multiple platform and new technologies emphasis within the IODP.

Past success of drilling hydrothermally active areas has been greatest when areas of fresh, glassy lava flows were avoided. Coarser grained or clay-altered rocks as well as hydrothermal mounds and sedimented systems are much easier to spud into, so those make more viable drilling targets. Areas that meet those criteria are the TAG and Lucky Strike hydrothermal fields on the Mid-Atlantic Ridge as well as some of the hydrothermal vent fields in back-arc basins in the presence (e.g., Okinawa Trough) or absence (e.g., PACMANUS) of sediments.

3.3. Life in extreme environments: strategies and adaptations (WG3a, WG3b)

The objective of the third working group was to discuss the organization of integrated multidisciplinary experiments on model environments, with emphasis on the biological, biogeochemical and geochemical processes sustaining life in extreme hydrothermal conditions.

The large number of participants for this working group illustrated the importance of this topic in current deep-sea vent researches and reflected the wide range of issues related to the adaptation of vent organisms to environmental extremes (e.g., chemoautotrophy, heavy metals detoxification, thermotolerance, symbiosis, respiratory adaptation in metozaons, relation to life cycles, etc.). To facilitate the discussion, the WG3 was divided in two sub-groups, while some joint discussions were also held.

The first sub-group was dedicated to vent-associated environments located below the seawater-substrate interface, e.g., at the rock/seawater interface, within sediments, within walls of white and black smoker chimneys, as well as within the crust where seawater and upwelling vent fluids mix. As most of these habitats cannot be directly accessed with tools or sensors, there is a common need to develop indirect approaches (biological and chemical characterization of fluids exiting the substrate, or of conditions at bounds of chimney walls, and modelling to infer *in situ* conditions) and dedicated sampling approaches (drilling at various scales, or allowing sensors to become embedded in growing structures). These environments are highly diverse in terms of thermal and chemical ranges, as well as in their vertical and horizontal dimensions. This poses unique challenges not only for the organisms inhabiting these environments, but also for sampling and studying them. In addition, at many locations there is temporal variability of boundary conditions, from geologic/tectonic perturbations, and/or from the ubiquitous periodic variability of bottom currents (often of tidal frequency).

To address these issues, the discussion group noted a need to take detailed measurements of boundaries when sampling, and also to take multiple measurements to characterize boundaries, rather than just spot measurements. The discussion group felt that to advance the field requires the integration of laboratory/shipboard experiments with *in situ* experimentation and measurements as well as modelling studies. In addition, the need for good descriptive observations/measurements of recovered material (e.g., mineral composition and zonation, porosity, presence or absence of fauna or fossil remains within zones) was recognized.

The group also noted the need for obtaining data on rates (e.g., to refine geochemical models and to improve estimates of biomass production). Examples of needed laboratory experiments include the measurements of rates at optimal and suboptimal conditions, as well as examination of sensitivity to temperature, pH, and different chemical species. Better constraints are needed on growth efficiencies of microbes to refine models that consider available metabolic energy. Experiments with defined cultures have the advantage that it can be determined which genes are expressed under certain conditions or which genes are expressed in the presence of multiple energy sources, enabling us to better understand adaptations of microbes in the natural environment. Better constraints are also needed for abiotic reaction rates (e.g., precipitation and dissolution of minerals). To better understand activity and metabolic rates will require the use of stable- and radioisotopes, as well as gene expression studies. The latter requires fixation of samples *in situ*, something that has been or is currently being developed in different laboratories. However, even with fixation *in situ*, sampling artifacts will be introduced (e.g., intake of seawater due to contraction of hot fluid within a newly sampled chimney as it cools) that need to be acknowledged. Most of the approaches listed above are still very challenging at sites of diffuse flow from unsedimented crust, or from chimney structures. It was noted that sites with venting through hydrothermal sediments (e.g., Logatchev, Guaymas, Middle Valley, Escanaba) might be good testbeds for developing and initially testing some of these methods.

The significance of identifying the important microbial players in the various habitats was also discussed in light of the great strides made in the last decade. At present, however, we still lack a good understanding of what these organisms are doing, and the rates of their catalyzed reactions. It will thus be important to (1) quantify microorganisms, (2) assess whether these organisms are active in their environment (e.g., by analyzing RNA, intact polar lipids or gene expression), and (3) implement studies that couple the identity of microorganisms more directly with their function. The methodology to address the latter has been developed (see e.g., stable isotope probing, MICRO-CARDFISH), but so far has largely not been applied to deep-sea hydrothermal vents. This is mainly due to the fact that conducting these studies at vents represents a great challenge, particularly in light of the physical, chemical and biological heterogeneity of these systems. Also metagenomic and eventually proteomic approaches offer much promise to further elucidate functional aspects, especially in combination with genomes of well-characterized organisms from these environments. This brings up the continued need to cultivate organisms, preferably at close to *in situ* conditions. Only with cultures will we be able to study their physiology and adaptations and identify genes and proteins expressed under defined conditions. Besides pure cultures we also need to consider communities, as some processes might be only carried out by synergistic association.

The group also discussed the disconnect between the scales at which measurements are made, and the scales at which microbes reside. Microbes may largely live in mineral boundary layers where the fluid composition is likely to deviate from the bulk fluid composition. Thus, the need for *in situ* measurements of physicochemical parameters at small scales was emphasized. There has been great progress being made in measuring a variety of physicochemical parameters *in situ* (e.g., T, pH, H_2S, H_2, Fe, FeS, $S_2O_3^{2-}$) at relatively small scale and also over time. Other sensors that would be highly desirable include ones that could measure CH_4, SO_4^{2-}, NO_3^-, PO_4^{3-}, NH_4^+, NO_2^-, Eh, and fluid flux. In addition, being able to measure metals like Cu, Zn, Cu, Hg, Mn would be important, in particular when the sensor would be part of an array in a chimney wall. At present different sample sizes are needed for analyzing microbial diversity and function (on the order of 100 ml) versus much less for some sensors. In the future, single cell genomics might be a solution to this discrepancy, potentially allowing us to understand processes at the scale of microbes. In its discussion of the importance of *in situ* measurements, the group noted the need for an international center for accessing complex/expensive tools and for learning how to use them properly to allow standardized measurements.

The second WG3 subgroup considered the environments located above the seawater-substrate interface (i.e., on the seafloor and surface of active or inactive hydrothermal deposits). Vent invertebrate communities provide unique models to study how metazoans adapt to environmental extremes. This subgroup focused on the interactions between model invertebrate species and their chemical and physical environment, taking into account associated microbes and particularly symbionts that sustain the exceptional productivity of these environments.

Although the physiology and diversity of endosymbioses have been extensively studied, the role of invertebrates themselves as biogeochemical drivers has been largely ignored. Their assemblages support substantial rates of electron donor and acceptor consumption, as well as metabolite elimination (such as H^+ for *Riftia*). However, still largely unknown is the contribution of these animals to biogeochemical cycling and fluxes, and their impact on the chemistry of the environment over scales ranging from associated microbial habitats to the vent field. The potential buffering effects of key-invertebrate species on the environmental extremes also need to be better addressed.

It was also emphasized that physical processes still primarily drive both the rate of electron donors and acceptors supplied to the communities, and the physico-chemical ranges to which the organisms are exposed. At larger scales, the ability of larvae to disperse and settle back in a suitable habitat is also largely related to physical processes. We need a better understanding of the physics of the system. The turbulent character of hydrothermal venting makes it a particularly difficult environment to model. Furthermore, a prerequisite to this modelling is to acquire accurate flow rate measurements at relevant scales, for which fully operational measuring devices are not yet reality.

Given this perspective, the research community needs to make new measurements, technologies and sampling strategies a priority. One main requirement was to enlarge the range of chemical and physical parameters to be measured *in situ*. In addition to the first priority parameters currently measured (like sulfide and oxygen or pH), other chemical parameters such as N or P compounds (NO_3^-, NH_4^+, PO_4^{3-}) are needed if we are to appreciate their potential impact on biological activity and the chemistry of the environment. Along with single parameter measurement methods implemented through colorimetric analyzers or (micro-) electrodes, multiparameter techniques like voltammetry and mass spectrometry are now operational for the study of vent invertebrate habitats. These techniques should allow a more complete description of the chemical environment, while preserving a high spatial resolution of measurements.

The adaptation of new techniques like those used in sedimentary systems for the simultaneous measurement of a 1D gradient or 2D chemical mapping (micro-arrays, planar optodes) would also be extremely useful to monitor the evolution of spatial gradients at the scale of organisms in time. Providing that more energy is made available (like in the context of seafloor observatories), innovative solutions may come from techniques currently used in industrial process like chemical imaging using video and spectral analysis. Flow measurement is still a critical point. Various prototypes have been implemented at different scales (e.g., sonar, different types of flowmeters) and may announce significant progress in the near future.

If the response of animals to their environment can be partly addressed *in situ* from the association of behavioral studies (short time response of organisms) and chemical monitoring, gene expression needs to be studied in the lab. Sampling of animals while minimizing stress for *in vivo* studies, or including *in situ* preservation, remains a great challenge. A few systems are now available for the preservation of biological samples *in situ*, some of them being adapted to small animals.

It was agreed that international cooperation should help to address these challenges. Benefits should particularly be gained from:

► Focusing efforts on target sites (like the ISS selected by R2K for the US community but at an international level). Well known sites with similar biological key-species but contrasted physico-chemical environments, like EPR 9°N and 13°N vent fields that are known to display marked intra-field variability in fluid composition, are particularly relevant to address biogeochemical interactions. Such 'natural laboratories' provide ideal conditions for *in situ* or *in vivo* experiments. Among the other possibilities for future collaborative projects is the MOMAR area with its 3 vent fields hosted on different geological settings; of these three, Rainbow offers unique conditions to study selective adaptation to alternative energy sources (hydrogen and iron oxidation) as well as toxic chemical exposure. Back-arc basins may offer interesting sites like the NBC vent on the mid-Okinawa trough, which may enable scientists to study a unique combination of different symbioses at the scale of a chimney.

► Comparison of existing *in situ* measurement techniques. A direct comparison of sensors is difficult to achieve in such a steeply changing environment. The consistency of data sets is more relevant to validate measurements. The more data sets we could get through enlarged at-sea collaboration, the more efficient the validation will be.

► Both *in situ* and *in vivo* monitoring approaches and experiments would largely benefit from the development of common instrumentation platforms (e.g. landers w/autonomous sensors, tanks with mass specs for respirometry control, dedicated sampling bioboxes). 'Centers of excellence' could be supported to drive the transfer of technologies, training of students/users, and provide facilities (e.g., test-bed for sensors). These 'centers of excellence' could be combined to observatory/natural laboratory sites.

► Sharing of money and facility access for genomic works (sequencing) should be encouraged. The InterRidge web page could be used to inform and to avoid duplication.

The working group (WG3a and b) further discussed the idea of conducting a vent field-scale experiment to address the outstanding question of how much biomass is produced at a vent system. Included in this assessment is how much biomass is consumed within the system, exported to the surrounding deep-sea, and how much production occurs above vs. below the seafloor, or through free-living microbes vs. symbioses.

While thermodynamic modelling allows us to perform theoretical calculations of available metabolic energy to place an upper constraint on the amount of biomass that can be produced in the system, we currently do not know how much of that is actually realized. To address these issues, it was proposed to characterize autotrophic rates within individual chimneys, diffuse flow patches, and communities at a particular vent field. Subsequently, the vent field would be systematically mapped (geophysical mapping, chemistry, temperature, fluid flux, microbes, megafauna) and the measurements integrated to estimate flux through the system.

A complement to this approach relies on the implementation of a core set of experiments at different vent fields that would allow us to compare how the biological and biogeochemical processes interplay and control these fluxes. A comparison of different vent system contribution to the oceanic carbon cycle and of the related mechanisms could be proposed.

These data would also be very useful to identify the best drill site for directly assessing the subsurface biosphere (see WG2). In addition to deep drilling, potentially using an “endoscope” with sensors and an intake to snake down into the subsurface or shallow drilling, might be powerful tools to advance our understanding of the subseafloor.

3.4. Observatories: tools and strategies for long-term seafloor ecosystems studies (WG4)

The goal of this session was to summarize existing tools and on-going developments, as well as make the case for needed technology breakthroughs for future studies. This session took advantage of a broad cross-disciplinary participation of scientists and engineers from the both IR community and other related fields.

The purpose of this working group was to discuss the current status of cabled network observatories to hydrothermal vent sites in the northeastern Pacific Ocean (*i.e.*, the US regional cabled observatory, or NEPTUNE) and the mid-Atlantic Ridge (*i.e.*, ESONET system to MoMAR) and strategies for biogeochemical experiments using this technology.

The advantages of running experiments using a cabled network include: a much larger power supply for instrumentation (compared to battery-driven instruments), and the ability to make, retrieve, and respond to observations in real time. Cable deployment has begun on the Canadian portion of NEPTUNE, and cable-laying is expected to begin in 2010 on the US portion. The EU is proposing non-cabled demonstration proposals within the ESONET Network of Excellence for the deployment of pilot experiments at the MoMAR site in 2009 and 2010. The US RIDGE community will meet at a workshop in March 2008 and will, in part, continue its discussions on how the US can coordinate its efforts to begin research at the MoMAR site in conjunction with the European efforts.

The working group stressed the importance of using the observatories to answer hypothesis-driven research. The kinds of questions that could be addressed more thoroughly using the observatory approach include: 1) successional, cyclic (*e.g.*, seasonal), and singular events that impact the system, 2) fluid and chemical fluxes, and 3) linkages with the water column. Specific questions include:

- How does microseismicity impact fluid flow and chemistry, microbial community composition and metabolic reactions, and faunal communities?

- What transient processes are occurring at vent sites that cannot be observed during a single cruise?
- What effect does light of varying wavelengths have on the behavior of macrofauna? Do we need to observe macrofauna communities at vents using specific light wavelengths to see them under more normal behavioral conditions?

In order to run these experiments using a cabled system, new instruments and coordinated arrays of instruments would need to be developed. In order to correlate chemical and microbial community compositions, fluid samples would need to be collected and sent to the surface for retrieval. There is a need for a mobile sampling platform that could be directed remotely to specific sampling sites. Fluid samples would need to be preserved and then released to the surface for either air or sea-surface recovery. Sensors also need to be developed that could transmit this information directly through the cable. Two- and three-dimensional sensor arrays would need to be deployed over a defined target area with coordinated imagery and chemical sensing from a mobile platform (*e.g.*, AUV) that would fly a regular pattern over the target area and transmit its data to land through a docking station. The cabled observatory would need to be calibrated and validated routinely through non-cabled surveys and methods would need to be developed to overcome biofouling issues. The working group also strongly recommends that a common core package of instruments be deployed at each of the cabled vent sites for direct cross correlation of the data retrieved from the sites. Successful cabled observatories will require a phased approach and long-term commitments for deployment and maintenance. There is also a need to continue developing strategies for how the data from the observatory will be processed, managed, and disseminated to the broader community and public.

3.5. New approaches and tools for biological and chemical sensing (WG5)

This lively working group discussion was spread over the final two days of the meeting. The group had a basic outline for discussion which started with a review of existing sensor technologies, then included those we had heard about as talks during the weeks, but also provided an opportunity for others that had not presented to do a 2-3 slide overview of their current work. This was followed by what turned out to be the longest part of the talk, that of composing a 'wish list' of sensors to further our research at hydrothermal sites. We then moved on to a discussion about issues of data management and platform integration, funding requirements, and then concluded the meeting.

Of the technologies in development we heard of some exciting prospects for increasing the range of analytes that can be determined by more 'solid-state' methods, such as electrodes and the potential for the development of sensors based on equilibrium chemistry. The potential for using systems such as Raman spectroscopy, GCMS and LIBS was discussed, and there is a very active program for these systems at WHOI and other institutions. We explored the opportunities for the adoption of sensors used in other fields of science and industry, and the potential to make our existing sensors more 'black-box' in operation to allow more widespread use both within our field and without.

The wish list was compiled as part of a lively discussion. There are a range of chemicals that we need to measure, including H_2, O_2, H_2S, CH_4, CO_2, T, SO_4, Cl, Fe, Mn, NH_4, PO_4, NO_3, NO_2, Org C, Zn, Cu, Hg, Si, Mg along with pH and Eh. Reliable methods for the determination of fluid flux are needed, along with methods to determine the rates of oxidation and reduction. The biologists in the group were interested in the development of *in situ* methods for FISH, cell counts, particle measurements and organismal identification methods. From discussions within the group it was clear that a large number of these techniques are in development for hydrothermal systems, or are used by other groups working in the upper ocean and can be adapted for our deep-sea application. To obtain a focal point for future sensor development, we polled the group for a short list from this larger wish list to obtain measurements we require/desire the most. These came down to pH, temperature (both at the high and low end of the spectrum), O_2, H_2S, H_2 and flow rate.

With the development of the deep-sea observatories in both North America and Europe, we can see a positive momentum behind sensor development. We as a group expressed a desire to enable the integration of sensors between platforms and countries through the use of standardised electrical operation and integration, possible by adopting ISO or ANSI protocols from industry. We also discussed issues related to data management, because with increasing use of sensors there is a potential for huge increases in data, which must be processed. The observatory networks have been proposed as open systems and as since much of the data produced will be in the public domain, this raises questions of IP rights, quality control and use of the data in publications; these issues must be addressed before the instruments are deployed on the networks.

The development of the networks proposed will hopefully lead to an increased realisation that we are lacking in sensor technologies that we can deploy on these networks. Getting funding for sensor development has always been challenging; funding agencies generally work on a 3-5 year basis, whereas most sensors take at least 10 years for development. As users and developers, we must lobby more effectively to change this approach. The formation of a centre of excellence, be it real or in the virtual world, would be a positive way of addressing not only the issue of lobbying for funding but also most of the issues raised in this working group.

We ended on the positive note that there is a growing desire to develop sensors not only in our field but also across all of the environmental sciences.

4. Conclusion

The highly diverse deep-sea hydrothermal environments have provided unique models to study biological processes and their reciprocal relationship with biogeochemical element cycling; our understanding will continue to develop as new vent fields and new types of hydrothermalism are discovered. The impact of these interactions occurs over a wide range of spatial scales (e.g., from the scales of microbial consortia to those of seafloor and subseafloor ecosystems, and possibly up to ocean basin scales). Thirty years after the discovery of vents, however, we still know relatively little about the mechanisms and rates driving energy and chemical element transfer in these environments, and their impact to the global ocean biogeochemistry. One main reason is the study challenge inherent in the spatial and temporal heterogeneity of hydrothermal biogeochemical systems. In conclusion, it was agreed that while great advances have been made in the understanding of the biogeochemistry of hydrothermal systems, great challenges still lie ahead.

The different working groups focused on the ways we can more efficiently address biogeochemical interactions and their impact on the sub-seafloor, seafloor and pelagic ecosystems. It was clear from these discussions and from the success of the IRTI itself that collaborative interdisciplinary approaches are essential. As obvious links were emphasized between sub-seafloor, seafloor and water column studies, it was also recognized that InterRidge researchers must seek integrated strategies—such as those employed by the Ridge community. We also need to develop common tools including new sampling techniques, chemical and biological sensing, and standardized procedures.

The working group discussions provided an opportunity to plan specific, IR-scale multi-disciplinary contributions to international programs such as GEOTRACES or IODP. In the future, the research community needs to identify and implement a standard set of measurements and experiments at selected vent fields in order to make better comparisons between studies, and global assessments as well. We felt that the field would benefit from a more coordinated international effort to address outstanding issues and develop synergies between national programs. Specifically, we discussed the idea of an international initiative that could be similar in structure to JGOFS or WOCE, to advance the field by carrying out similar studies with standardized methods at multiple vent fields. Only then will we be able to characterize biogeochemical mechanisms and fluxes at vents, and quantify their input to deep/mid-ocean chemical and biogeochemical cycles. As a first step toward this goal we discussed the possibility of a SCOR working group on this topic.