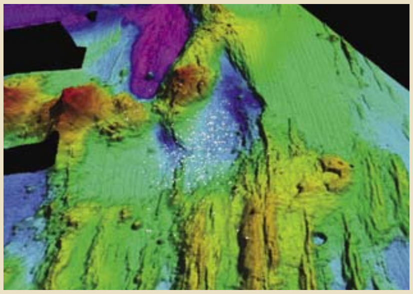
Ridge 2000 Events

A Newsletter of Ridge 2000 Program

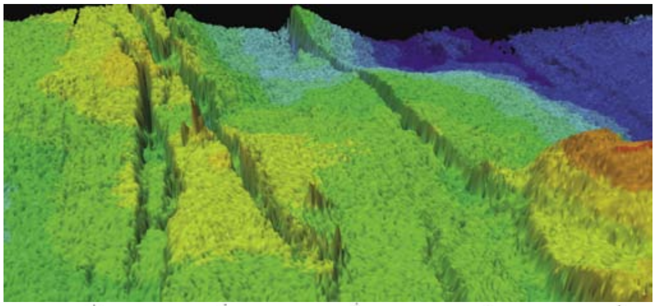
VOLUME 3 SPRING 2005

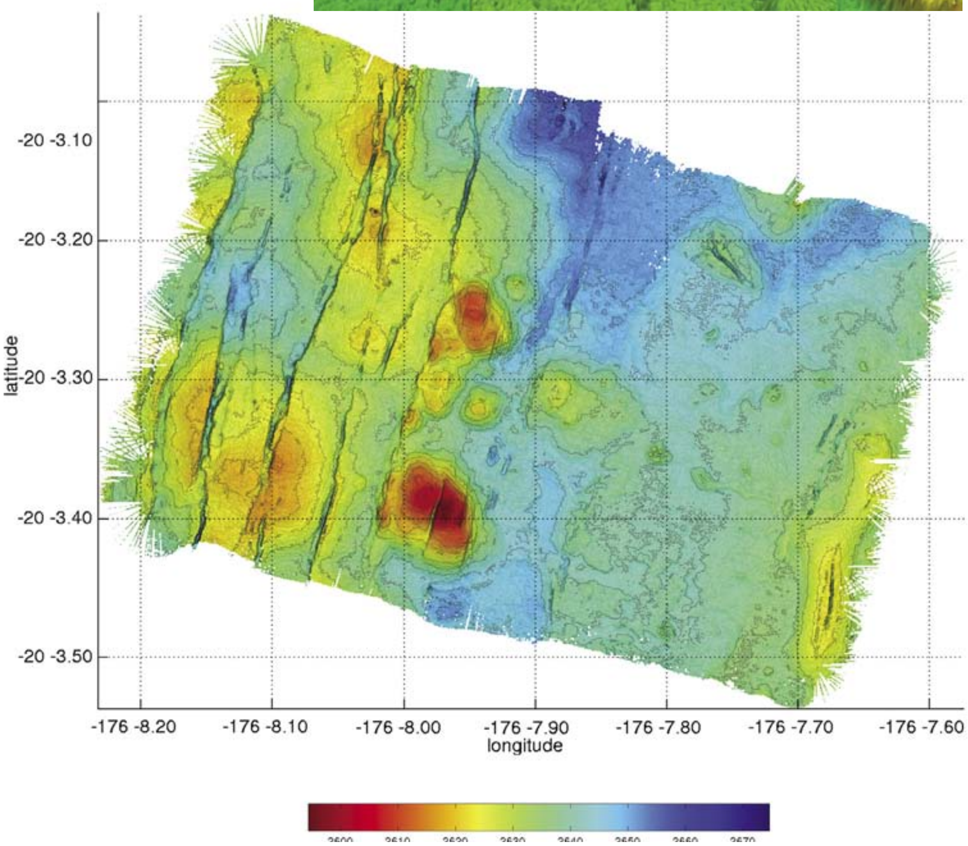
In this Issue



Oblique 3D view of the February-March 2005 earthquake swarm area on the Endeavour Segment, Juan de Fuca Ridge. See related article on page 14.

Masthead Photo—Sampling water from vent Bio9' at 9°50'N on the East Pacific Rise. Courtesy of Karen Von Damm, from January 2002 EPR cruise.





On the cover

Lau Basin cruise 2 located three new vent fields and shared discovery of a fourth field with a Japanese science team in September 2004. PI C. Langmuir deployed ABE, the Autonomous Benthic Explorer, in an innovative three-phased approach from 300 m, 50 m, and 5 to 10 m above bottom to survey water column properties, produce high-resolution bathymetry, and photograph the seafloor. The microbathymetry of site 1 (above), named "Kilo Moana," shows canyons in the seafloor running north to south, vents lining a scarp, and a 20-m spire at the same location where water chemistry spikes indicating active venting had been found in an earlier phase. Site 1 was selected for further study from the maps and water column data collected on cruise 1 in May 2004 (PI: F. Martinez). (Images courtesy of C. Langmuir, Harvard University. See related article on page 11.)

From the Chair

Charles Fisher, *Ridge 2000 Program Chair*

Dear Ridge Scientist,

I have recently returned from both our own Steering Committee meeting and that of the InterRidge Program. They were both invigorating. The InterRidge Program is quite healthy, and the gathering momentum of the new Ridge Programs in India, China, and Korea will add considerably to international research efforts on oceanic spreading centers around the world.

As you will see in this newsletter, all three of the Integrated Study Sites (ISS) are flourishing. Like fine wines, each has its own flavors, strengths, and maturity. At the Lau ISS the first two cruises went off like clockwork. During a cruise led by Fernando Martinez, the bathymetry of the entire East Lau Spreading Center (ELSC) was mapped in nested detail, and numerous new plumes were discovered along the length of the ridge. During the next cruise led by Charlie Langmuir, three very promising new vent sites were pinpointed and imaged in the northern portion of the spreading center and collaborations with Japanese scientists led to descriptions of several more sites in the south. At this writing, Meg Tivey is at sea with another team of R2K scientists diving on these sites with *Jason II* to complete hydrothermal, geological, and biological studies. Results from this program will set the stage for biologically oriented cruises that will follow. Each of the teams has unselfishly shared unpublished data and insightful interpretations that were indispensable to the following cruises. The collaborations with Japanese scientists benefitted both Ken Takai and his team, as well as our R2K efforts. We were able to provide details of bathymetry and plume locations to the Japanese team (some data collected only days before they arrived on site), and the Japanese scientists provided us with detailed descriptions of discoveries made during 16 dives with the *Shinkai 6500* in the Valu Fa region. As co-chief scientist of the final cruise this year, I only hope that we can live up to the very high standards set by our predecessors.

On the EPR ISS in 2004, six cruises went to sea, with eleven funded programs and even more PIs. Two of these cruises were primarily funded outside of the R2K program, but all provided contributions toward an understanding of the integrated system and all benefitted from the interdisciplinary studies underway at the site. This trend will continue through 2005 and 2006 when additional projects come on line, all well integrated into program goals and providing data integral to our understanding of this ISS. Funded programs at the site include mantle and hydrothermal system imaging studies, a wide variety of linked monitoring and manipulative experimental work centered at the site bull's eye, and related microbiological and modeling studies.

The Endeavour ISS is flourishing with numerous funded studies aimed literally at everything from the "mantle to the microbes," and the excitement over the upcoming access to be provided from the NEPTUNE Canada cable is palpable. Numerous instruments are on the seafloor at Endeavour and plans are being made for their transition to cabled operation in the near future. The NEPTUNE Canada cable project has been funded by the Canadian Foundation for Innovation and current plans include installation of the network in 2007-2008. Now is the time to get your instruments ready for a reliable power supply and two-way real-time communication! One of the reasons for the success of the Endeavour ISS to date has been the unrelenting efforts of scientists working at this site to bring in funding from other sources to reach the science goals of the R2K program. This issue of the Ridge 2000 newsletter highlights the Endeavour ISS (future issues will highlight other sites). When you read the Endeavour update you will appreciate how projects funded outside of the NSF have been central to the success of this ISS.

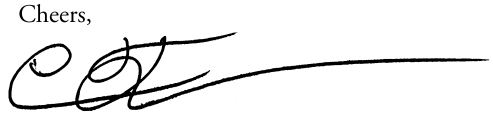
As many of you know the Time Critical Studies rapid response community saw action just last March. An earthquake swarm near the northern Endeavour Segment began early morning on February 27, 2005, and continued for a total of 3,740 detected earthquakes over a 5.5-day period. After considerable consultation and debate, and only 6 days after the start of the swarm, the rapid response team was on station aboard the RV *Thomas Thompson* conducting water column surveys. Before the cruise ended a week later, high-resolution multibeam and towed camera images of the seafloor had been added to the collected data. Although the team detected no evidence of a new lava flow, or event-related hydrothermal discharge, the magnitude of the response mounted in only six days demonstrates the vitality of the program and the dedication of the scientists and funding agencies involved. The steering committee heard a report from Jim Cowen on the response effort. After unanimously recommending that they keep up the good work, we were pleased to hear that the team could be ready for another response "tomorrow."

Under the direction of Liz Goehring, and with the overflowing energy of Dr. Catherine Williams and Greta Mertz, our Education and Outreach programs are racing forward. Liz is at sea with the Student Experiment At Sea (SEAS) program on the EPR as we go to press, while Catherine and Greta continue to improve our website and follow both SEAS and the Lau cruises on the website. Patty Nordstrom and Sharon Givens have been working overtime to take care of the many meetings, workshops, and field trips we have helped organize, and both deserve our thanks. Finally, thanks to Donna Blackman of Scripps, who was elected and has agreed to chair the Steering Committee and R2K Program office when the office rotates in November. Donna has been a very active member of the Steering Committee for the past 3 years and has already begun to take on a variety of tasks she could have quite reasonably put off for another 6 months (thanks again Donna).

As a last note, thanks to all of you. Although I will remain chair of the program until November, this will be my last "message from the chair." It is a pleasure working with such a dynamic and interdisciplinary community, and an honor to represent you both here and abroad. It has been fun and I've learned a lot, and no one can ask for more from work (or play).

You are the Ridge 2000 program and the reason that it is flourishing now and will continue to grow regardless of budgets, ship schedules, or tectonic/magmatic events. Keep up the great work, and keep those proposals coming.

Cheers,



Ridge 2000 Education and Outreach

Liz Goehring and Catherine Williams

Promoting the fascinating work of the Ridge 2000 community to different audiences is an exciting and challenging process. This article focuses on two of the main efforts of the Ridge 2000 Education and Outreach program—the K-12 education program, SEAS, and the new public website, www.venturedeepocean.org.

SEAS: Student Experiments At Sea

If NASA can take student experiments to space (and capture the hearts and minds of countless others in the process), why can't we take students' experiments to the bottom of the ocean? The answer is a definite, "We can!"

SEAS is a pilot education outreach program for the Ridge 2000 community that offers scientists several easy and rewarding ways to meet the NSF Broader Impacts criterion. SEAS builds upon the successes of programs like REVEL, Dive & Discover, and Extreme2000, which demonstrate deep-sea scientists' capacity to engage students and teachers with "live" research. SEAS not only exposes middle and high school students to real research, it offers them the chance to get involved themselves—by designing their own deep-sea experiments and/or by analyzing and reporting on real deep-sea data. SEAS includes a curriculum, fully developed website, motivating labs and competitions, and professional development workshops to support teachers using SEAS.

Student contact with Ridge 2000 scientists is *integral* to the program, and there are a variety of ways for scientists to become involved. Students proposing experiments to be performed at sea are able to discuss (via email) their ideas with Ridge 2000 scientists before submitting written proposals. Scientists provide feedback on proposals, and choose up to five experiments to be performed at sea. Scientists work with classes to refine winning proposals so that experiments can be undertaken, and then host student experiments on their research cruises. There are also opportunities to serve as mentors. An open report competition at the end of the school year encourages students to analyze and reflect on data from these experiments; scientists provide feedback on reports and choose winners in several categories. Scientists also teach key components of the teacher professional development courses.

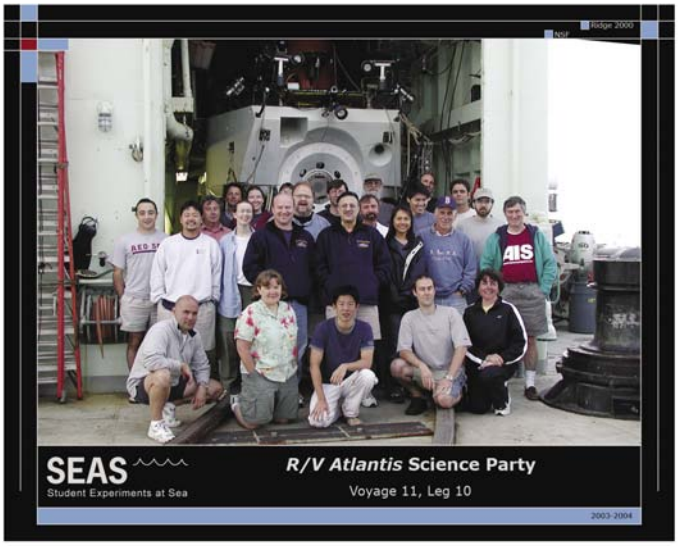


Fig. 1. Many thanks to the SEAS cruise hosts, especially PIs Rich Lutz, Costas Vetriani, Tim Shank, and George Luther.

Why was SEAS created?

To help address needs in today's science classrooms. One of the most important buzzwords in U.S. science classrooms today is *inquiry*. Inquiry involves developing questions based on observations, formulating hypotheses, designing experiments to test hypotheses, and using data generated by the experiment to support or refute the hypotheses. Science teachers across the country are required to teach inquiry, although they may have little or no direct experience with it themselves.

SEAS uses the research conducted by the Ridge 2000 community to model the process of inquiry for students. The SEAS curriculum shows teachers step-by-step how to guide students in inquiry. Further, the program invites students to "learn by doing" in the exciting field of deep-sea research. Working alongside scientists is truly inspiring to middle and high school students.

To provide avenues for outreach for Ridge 2000 scientists, and to promote the Ridge 2000 Program. The *National Science Education Standards* (National Research Council, 1996) calls for scientists to get involved in K-12 education. NSF's Broader Impacts criterion also encourages scientist involvement. SEAS offers a framework for Ridge 2000 scientists to contribute to science education in very meaningful ways. And in the process, SEAS showcases the exciting research of the deep sea.

SEAS to date

SEAS was launched in 2003 and piloted with the help of an NSF grant. In 2004, the Ridge 2000 E&O program received a second grant from NSF to continue the SEAS pilot, particularly focusing on teacher professional development and program evaluation. After a year of successes and lessons learned, it is time to determine if we are indeed achieving our goals—to excite and engage students with ocean sciences and to foster authentic student scientific inquiry. Initial feedback from the program evaluation suggests we are doing just that. One teacher involved with the program last year cites SEAS as the reason a majority of her students are now saying they want to go into oceanography-related careers, something she's not seen before in all her years of teaching ocean sciences. Another teacher said that working with SEAS has prompted a paradigm shift for her and her students. They used to regard experimentation as a linear process with a known outcome (even to the point that students would alter data if they didn't get the results they expected!). Now, she and her students understand that experimental outcomes can be unknown, that experiments are designed to collect data that may falsify hypotheses, and that the inquiry process involves feedback from others at many different stages. And they are loving the excitement of discovery.

SEAS needs you!

SEAS needs you, Ridge 2000 scientists, to participate. For example, SEAS needs cruise hosts, "Ask-a-Scientist" volunteers, proposal and report reviewers, curriculum reviewers, mentors, and course lecturers for the teacher education component. We are offering two teacher courses this summer (at Penn State, University Park, PA, and at the Ocean Institute in Dana Point, CA) and would welcome your involvement.

By sharing the load, no one individual is too heavily burdened, and each contribution helps you satisfy NSF's Broader Impacts criterion. You will continue to hear from us soliciting your involvement (through the Ridge 2000 website and mailing list), and we encourage you to contact us directly. Many, many thanks to those of you who are already involved.

A new year, a new general public approach online

The general public is one of three main audiences for Ridge 2000 Education & Outreach. In 2004, we launched a website specifically aimed at the public, www.southpacificodyssey.org, to report on the series of Lau Basin cruises in 2004/05. Many thanks to all of you who helped get this site live by contributing thoughts, material, and photographs.

The web, however, is a continually evolving medium, and Ridge 2000 online public outreach is no exception. In the breathing space between the second and third Lau cruises, with knowledge from the first two cruises under our belts and some new Internet expertise available to the Ridge 2000 Program office, we took the opportunity to reexamine our web offerings to the public. As part of this process, we reconsidered some of the strategic underpinnings of our public outreach, such as:

Priority audiences: Whom do we really want to target, and why?

Aims and outcomes: What do we want these people to know, feel, or do, and why?

Communication channels and propositions: How best do we reach them? When should we use the web and when are other channels better? What works best on the web?

Existing outreach: What is already being done, by whom, to get our key messages across to our target audiences? What do we want to do differently from existing efforts?

Following this review, we have refocused Ridge 2000 online public outreach. In particular, we have:

Fig. 2. Middle school students in Lexington, Massachusetts, work with a photomosaic of "Flying Buttress," a Juan de Fuca sulfide chimney structure. Thanks to Debbie Kelley and John Delaney, the mosaic is part of the SEAS pilot curriculum.

- **Redesigned the website, restructuring and repackaging content aimed at the public.** Not only is the site now easier to maintain and expand, but also it is easier for the target audience to understand and navigate. The redesign caters more effectively to the way that people prefer to read and navigate online [*Nielson,* 1997; *Krug,* 2000]. For instance, rather than long pages that need to be read sequentially, the site uses web-friendly devices such as short, hyperlinked pages, which can be viewed in a variety of sequences, with information-rich headings, bulleted lists, captioned photographs, and slide shows. Content has been broken into smaller units so it is easier to follow onscreen, high-level pages include more introductory-level content, and visitors can more easily control the level of detail they access.

- **Broadened the site's focus, and changed the name to reflect this.** The previous website focused on the Lau cruise series, but much of the scientific and technical background material is common to a broad range of Ridge 2000 studies. The new website will serve as a general introduction to spreading center systems, and can easily be expanded to feature other Ridge 2000 cruises as well as the Lau series. This will give the website longevity beyond the last Lau cruise, and provide a ready-made channel for online publicity surrounding other Ridge 2000 research. The broadened focus is reflected in a new name and URL, www.venturedeepocean.org (the previous URL is now redirecting visitors to the new site).

- **Included many links to relevant information on other websites.** Links provide interested visitors with other useful resources, without the effort of duplicating what is available online elsewhere.

- **Begun promoting the site more extensively, online and offline.** Even well-designed websites will not be visited unless people can find them. The site redesign, together with changes to hosting, will make search engines more likely to display our pages high in results lists, but we also want more links and signposts to the site—from offline material as well as online. If you or your organization have a website or other outreach material, please consider linking to www.venturedeepocean.org; we will likely be able to link back to you.

As well as conducting public outreach online, we want to continue to use non-Internet media to inform the public about Ridge 2000 science. Articles, interviews, and teasers in traditional media are still a powerful

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Status Report on the Endeavour ISS

Deborah Kelley *(U Washington), Site Coordinator*
David Butterfield *(U Washington/PMEL), Oversight Committee Chair*

The Endeavour: An Integrated Observatory

The Endeavour Integrated Studies Site (ISS) is the first mid-ocean ridge seafloor observatory where a diverse suite of in situ instruments are allowing long-term measurements of regional and local seismicity in conjunction with coregistered time-series measurements of vent effluent temperatures and chemistry, vent-field-scale heat and fluid fluxes, and time-series microbial and vent fluid sampling (Figure 1; Table 1). The success in this effort is in part due to significant funding from the W.M. Keck Foundation to support a 5-year proto-NEPTUNE Observatory program to study how seismicity and crustal deformation are linked to changes in fluid chemistry and microbial productivity. This effort, in concert with programs supported by the National Science Foundation, Monterey Bay Aquarium Research Institute, NOAA West Coast and Polar Regions Undersea Research Center, and Fisheries and Oceans Canada has lead to a number of important highlights:

- Documentation of over 12,000 earthquakes on the Endeavour Segment during the period 2003-2004, of which 3500 lie in the immediate vicinity of the fields.
- The first long-term deployment of a buried broadband seismometer at a volcanically hosted submarine hydrothermal system.
- The successful recovery of microbial incubators from within the walls of active black smoker chimneys. Over 600,000 temperatures were recorded on each instrument, one of which in Mothra showed significant, abrupt temperature perturbations. These events are currently being analyzed in the context of coregistered earthquake data.
- 18 ABE dives covering 367 km of track that resulted in high-resolution bathymetry maps of all five known hydrothermal fields on the Endeavour Segment, and measurement of the vertical fluxes of fluid mass, heat, and salt rising from the fields.
- Delineation of coherent basaltic flows within the axial valley that can be traced for > 1 km, collection of over 200 basaltic samples for petrologic and geochemical analyses and chronology, and recognition that off-axis volcanism is abundant. Endeavour has been volcanically active in the very recent past with similarities to Cleft.
- Apparent extreme increases in macrofaunal populations in the Main Endeavour Field (MEF), continued growth of nascent chimneys formed subsequent to the 1999–2000 events, and toppling of a 380°C chimney called Puffer. Fluids continue to be near or just below seawater salinity within the MEF, and volatiles have returned to pre-dike injection values.
- Prototype hydrophone experiment records first acoustic information from any mid-ocean ridge vent. Experiment in 360°C chimney, called Sully, in the MEF recorded loud and varying acoustic signals for 40 hrs. Potentially, this will provide valuable information on flow velocities and nature of flow in upflow conduits.

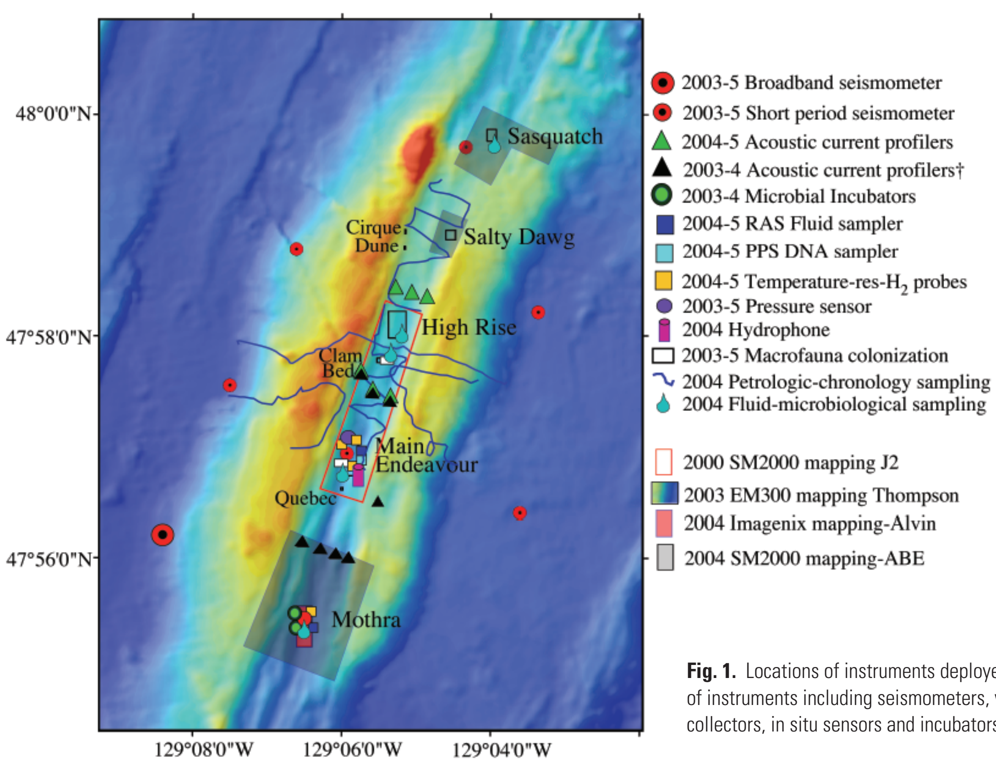


Fig. 1. Locations of instruments deployed at the Endeavour ISS since 2003. A wide range of instruments including seismometers, water current profilers, water and particulate DNA collectors, in situ sensors and incubators have been collecting data over the past two years.

- Entrainment and active participation by educators, students, and the public through the REVEL program, Dive and Discover, and a research apprenticeship class run by the University of Washington and the University of Oregon at the UW Friday Harbor Laboratory.

The success of these experimental, scientific, and outreach efforts highlights the power and importance of optimizing leveraging opportunities both nationally and internationally to enhance growth of the IS sites and to maintain their health. To this end, Endeavour is again in a key position to leverage significant funds for long-term, in situ crustal, chemical, and biological studies through the NEPTUNE Canada program. Canada has received ~ $62M CAN to begin installation of the fiber-optic cabled observatory NEPTUNE with the Endeavour as a likely node. Two proposals are now under consideration for funding at Endeavour through NEPTUNE Canada that involves numerous U.S. and Canadian researchers. Installation of the cable is expected in 2007-2008.

Progress at Endeavour During the 2004 Field Season

The spring and summer of 2004 were busy on the Endeavour with 8 cruises from May to September (Table 2) that employed *Alvin,* ABE, and two remotely operated vehicles, ROPOS and *Tiburon.* Currently, there are over 40 researchers involved in the Endeavour ISS from > 20 institutions across the US, Canada, Germany, Switzerland, and Japan. In the discussion below some of the results for the 2003-2004 field programs and educational outreach efforts are summarized, plans for the 2005 field season are presented, and future programs are outlined.

The Keck Experiment

The W.M. Keck Foundation NEPTUNE-prototype experiment is a collaborative effort, led by the University of Washington and involving scientists from the US and Canada [*Delaney et al.,* 2004]. The goal of this program is to explore a newly recognized process operative at the conjunction of the earth, ocean, and biological sciences. The basic premise is that when rock deforms, the nutrient-rich fluids set in motion are capable of supporting microbial blooms in adjacent portions of the crust or within the overlying ocean. While it is not possible to fully test this hypothesis without a permanent presence on the seafloor, the goals of the Keck experiment are:

1. To initiate such tests by deploying state-of-the-art networks of sensors and samplers at two locations (three plate boundaries) on the northern portion of the Juan de Fuca plate.

2. To develop critical new chemical and biological sensors that will provide the complete set of time-series observations necessary for longer-term studies.

3. To begin to solve the technological and scientific challenges of integrating multidisciplinary time-series observations.

4. To have in place a showcase experiment that will highlight the capabilities of NEPTUNE as soon as the northern portion of the cabled network is installed.

Table. 1. Instruments Deployed at Endeavour 2003-2005

Instrument	Location	Deployed/Recovered	Comments
7 short-period corehole seismometers (K)	Central portion of the hydrothermally-active Endeavour segment	Deployed in 2003 in drillholes and seismonuments, cycled in 2004, remain in place	Detected >12,000 earthquakes 2003-2004, good coupling to seafloor, all instruments worked
3 MBARI broadband seismometers with Guralp sensors (K)	W. flank Endeavour, Explorer Plate, Jdf Plate by Nootka -margin intersection	Deployed in 2003 and 2004, remain in place	Good recordings obtained for teleseismic and regional events
4 temperature-resistivity (chlorinity)-H_2 probes (K)	Main Endeavour Field: Hulk, Bastille, Sully Mothra: Faulty Towers Complex-Hot Harold	Deployed in 2004, remain in place	Temperature-resistivity components well established, H_2 component prototypes
2 McLane Fluid Samplers (K)	Main Emdeavour Field: Hulk Mothra: Cuchalainne Complex	MEF deployed 2003-2004, redeployed and still inplace, Mothra in place 2004-2005	Time-series fluid sampler took 48 samples and temperature, co-registered with particulate DNA
1 McLane Particulate DNA sampler (K)	Main Endeavour Field: Hulk	MEF deployed 2003-2004, redeployed and still in place, coupled directly with water sampler	Time-series filtered samples preserved in situ for particulate DNA, worked successfully
1 MAV current meter (NSF)*	Main Endeavour Field: Hulk	Deployed 2004, still in place	Adjacent to Mclane samplers for local current measurements
2 Sulfide-Microbial Incubators (NSF)†	Mothra Hydrothermal Field: Faulty Towers Complex Roane and Hot Harold	Deployed in 2003, recovered 2004, redeploy new prototypes 2005 (temperatue-osmo samplers-H_2)	Over 600,000 temperatures measured in each instrument, well defined gradients, significant temperature perturbations, sequencing successful
1 hydrophone (UW)	Main Endeavour Field: Sully	Deployed and recovered 2004	First time a significant acoustic signal measured in 360°C vent
1 Paroscientific Pressure Senor (NSF)	Main Endeavour Field: adjacent to short-period	Deployed 2003, cycled 2004, in place	Reliable instrument for recording pressure transients
5 current meter moorings, 3 up-looking acoustic current profilers (NSF)¥	Between Main Endeavour Field and Mothra Between Main Endeavour And Hi Rise	Deployed 2003-2004 Deployed 2004-2005	Coupled with 18 ABE dives and 42 distinct CTD's with over 1000 lowerings
2 macrofaunal colonization platforms (NSERC)	Main Endeavour Field: S&M Clam Bed	Deployed in 2003 Still in place	Part of on-going CanRidge experiment

*(K) = funded by the Keck Foundation; *On loan courtesy of S. Hataula, and H.P Johnson, † with additional support from the Keck Foundation and University of Washington; ¥Department of Ocean and Fisheries Canada is supplying additional ship time with the Coast Guard Vessel John P. Tully to recover and redeploy the instruments.*

Table. 2. Schedule of Completed 2004 Endeavour Field Work

Dates	Region (# of Dives)	PI	Ship/ Vehicle	Ports
	Endeavour (9)	Kelley OCE0221900		
May 24-June 10	Endeavour (2)	Brown OCE0241998	*Atlantis* *Alvin*	Seattle Seattle
	Endeavour (3)	Hilton OCE0242034		
June 15-July 14	Endeavour (34)	McDuff OCE0242736	*Atlantis* ABE	Seattle Seattle
July 30-August 13	Endeavour (10)	McGill/Wilcock MBARI	*Western Flyer* *Tiburon*	Newport Newport
August 16-August 27	Endeavour (9)	Girguis MBARI	*Western Flyer* *Tiburon*	Newport Newport
August 30-September 12	Cleft (5) Endeavour (5)	Gill NURP	*Western Flyer* *Tiburon*	Newport Newport
September 1-20 September 21-24	Endeavour (20) and Nootka IODP Flanks (3)	Delaney KECK Becker/Davis NSF	*Thompson* ROPOS	Portland Seattle

Keck Seismic Network Configuration and Preliminary Results

In comparison with other intermediate- and fast-spreading-rate ridges, the Endeavour Segment is characterized by very high levels of seismicity [*Dziak and Fox,* 1995; *Wilcock et al.,* 2002; *Wilcock,* 2004; *Barclay and Wilcock,* 2004]. The reasons for this are not fully understood, but at the segment scale this activity is probably related to the complex and

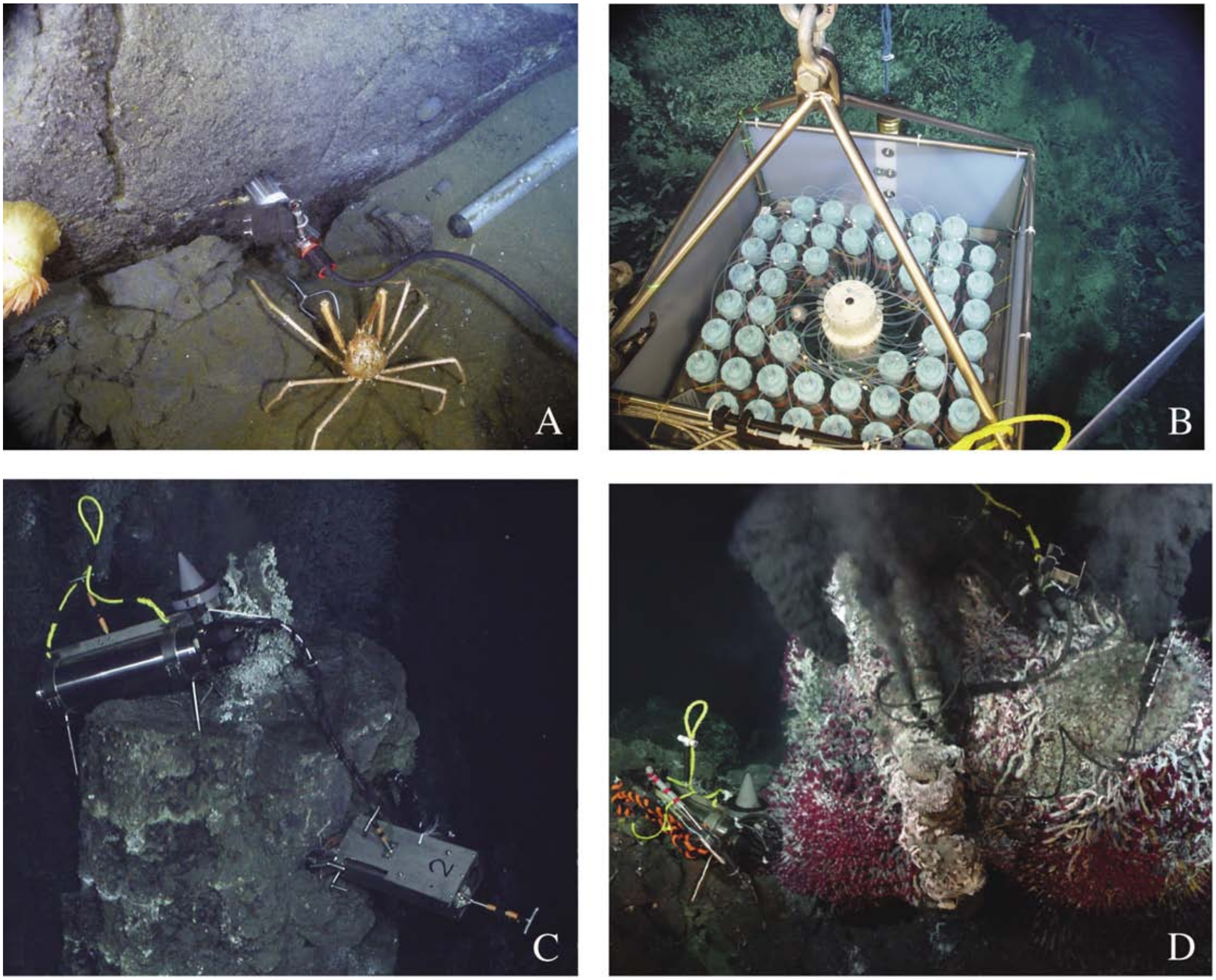


Fig. 2. Photographs of seafloor instruments deployed at Endeavour. (A) Short-period seismometer installed in basalt flow a few tens of meters east of the Faulty Towers Complex in the Mothra Hydrothermal Field. This instrument includes an MBARI/GEOSense sensor package (shown) and an MBARI/GEOSense LP1 logger and battery pack (out of field of view) [*Stakes et al.,* 1998]. The sensor utilizes a miniature geophone that can measure frequencies below 1 Hz. To deploy the sensor in bare rock environment, an ROV-mounted diamond drilling system is used to prepare a 7-cm diameter 30-40 cm deep, horizontal borehole in the basement rock. (B) McLane Remote Access Sampler just prior to installation at the diffuse field Clam Bed. The instrument was deployed near a sulfide mound for yearlong fluid time-series in 2003. (C) Microbial incubator installed inside the walls of the diffusely venting chimney, called "Roane," in the Faulty Towers Complex. The top ~ 2 meters of this chimney were recovered in 1998, yielding a flat platform for the data logger package. This instrument was recovered in 2004, following a 340-day deployment that yielded over 600,000 temperature measurements in three discrete chambers inside the chimney wall. Coupled phylogenetic-culturing–mineralogical analyses are being analyzed in context with coregistered temperature measurements. (D) A hydrophone deployed at the 360°C chimney, called "Sully," in the Main Endeavour Field. This instrument recorded sounds far louder than expected, with significant changes in both the acoustic intensity and in the spectral signature. The instrument to the left of the chimney is a temperature-hydrogen-resistivity (T-H-R) probe awaiting deployment. The-T-H-R probe was deployed summer 2004 and will be recovered in September 2005.

evolving tectonics of the Explorer Plate region [*Wilcock et al.,* 2002]. Beneath the Endeavour vent fields, the high levels of seismicity in the inferred location of the reaction zone make this the ideal site to study the linkages between seismic deformation and magma-driven hydrothermal circulation.

In the summer of 2003, the ROV ROPOS deployed one broadband and seven short-period seismometers in a local network (Figure 1) on the central portion of the Endeavour Segment. Five of the short-period sensors (Figure 2A) were placed in boreholes that had been drilled by the ROVs *Tiburon* and *Jason II,* while the remaining two were placed in concrete monuments (seismonuments). The broadband was buried in sediments on the west flank of the axial high about 2 km from the Main vent field. In August 2004, the ROV *Tiburon* was used to service the Endeavour seismic network and recover the first year of data. In addition, a second broadband and three short-period seismometers were installed on the Nootka fault on the Juan de Fuca Plate, and a third broadband seismometer was deployed on the Explorer Plate.

(A)

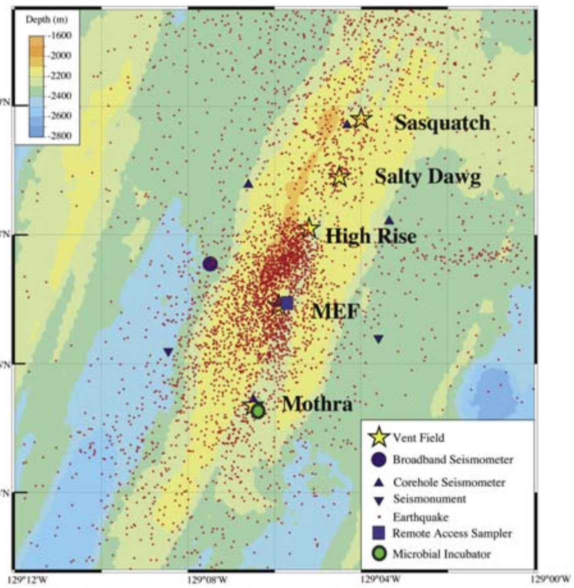
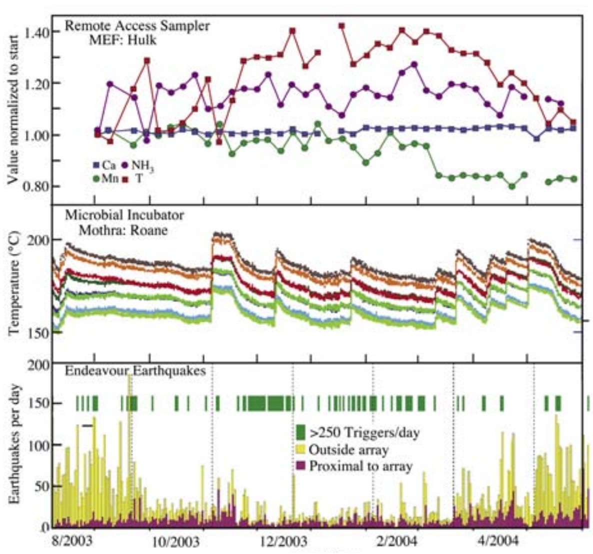


Fig. 3. (A) Map showing the locations of seismometers in the Keck Endeavour network and ~ 3500 epicenters within the vicinity of the Endeavour vent fields. Note the sharp drop off in seismicity north of the High Rise field. Also shown are the locations of the Remote Access Sampler and microbial incubator for which time series data is shown in B. (B) Three panels showing (1) fluid temperature (T) and chemistry near the sulfide chimney, "Hulk," in the Main Endeavour field, (2) temperature measurements within one of three chambers in a microbial incubator within the diffusely venting sulfide chimney, "Roane," in the Mothra field, and (3) the occurrence of earthquakes detected by the seismic network. All measurements are on the same time scale from 1 August 2003 to 31 May 2004. In the top panel, temperature and concentration data have been normalized (measured value/initial measured value) to the first hydrothermal sample collected at the start of the time-series to show relative change over the year. Middle panel shows recorded temperatures from nine thermocouples ~ 7 inches inside the wall of Roane. In addition to these measurements, an additional 18 thermocouples measured coregistered temperatures in two other chambers. All 27 probes recorded simultaneous perturbations in temperature multiple times during this experiment. Bottom panel displays a histogram of located earthquakes showing proximal events (within 3 km of the seismic array) in purple and events well outside the array in yellow. The green bars show days on which a short-term/long-term triggering algorithm detected > 250 events on at least three stations. Many whale vocalizations were detected during winter months. More detailed analysis of the location and timing of seismic events and the temperature and chemical data are being performed to look for correlations.

(B)



The Endeavour seismic network performed remarkably well with all eight instruments recording high-quality data. The noise levels on the broadband instrument compare favorably with other submarine installations and good recordings were obtained for both teleseismic and regional events. The local earthquakes are characterized by high-quality shear wave records, which reflect the good coupling to the seafloor obtained with ROV-deployed sensors.

Preliminary analysis of the data were undertaken during an undergraduate Research Apprenticeship class taught in the fall of 2004 at the Friday Harbor labs [*Wilcock et al.,* 2004; *McGill et al.,* 2004]. About 12,000 earthquakes were located on the Endeavour segment of which 3500 lie near the seismic network within < 3 km of the nearest station (Figures 1 and 3). The seismicity within the network appears to be concentrated above and to the west of the axial magma chamber at ~2.5 km depth, although further analysis will be required to refine the estimates of focal depth. One striking characteristic of the distribution of seismicity within the network is the high level of seismicity between the Main and High Rise vent fields and the sharp drop in seismicity north of High Rise (Figure 3A). The levels of seismicity appear to correlate with the vigor of venting.

Ongoing analysis will improve the preliminary locations within the network region by refining arrival time picks, using a more detailed velocity model, and calculating station corrections. A systematic search for volcanic tremor has been initiated and a number of interesting signals have been identified. The Keck investigators are also comparing the preliminary earthquake data with temperature and chemical time series observations (see below), although improved earthquake locations will be required to make robust correlations (Figure 3B).

Continued on page 17

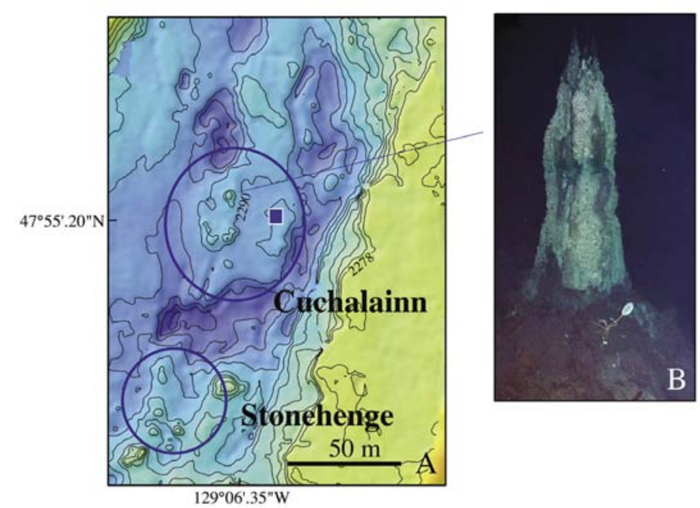


Fig. 4. This figure shows a small portion of high-resolution bathymetry collected within the Mothra field using the Imagenex sonar mounted on *Alvin* in 2004. Contour interval is 2 m. Also shown are the two most southern, actively venting sulfide clusters called Cuchalainn and Stonehenge. The small, rounded individual highs within the clusters are isolated chimneys with similar morphologies to the one shown in B. These fields are located in a region of extensive collapse adjacent to the western axial valley wall. The low relief area to the east (yellow) is composed of extensive lobate flows. Also shown is the location of a remote access sampler deployed in an area of diffuse flow since 2004 (blue square); it will be recovered in September 2005 during a Keck cruise. (B) Photomosaic of a diffusely venting sulfide chimney within Cuchalainn. Diffusely venting chimneys such as this provide a rich habitat for dense, micro- and macrofaunal communities. The marker at the base of the structure is on a 1-m long tether.

Status Report on the East Pacific Rise ISS

Suzanne Carbotte *(Lamont-Doherty Earth Observatory, Columbia U), Oversight Committee Chair*
Maya Tolstoy *(Lamont-Doherty Earth Observatory, Columbia U), Site Coordinator*

The 8°–11°N segment of the East Pacific Rise (EPR) represents a dynamic, fast-spreading portion of the mid-ocean ridge that encompasses diverse environments including a hierarchy of axial segments and discontinuities (Figure 1). The site "bull's eye" is at 9°49'–9°51'N where numerous high-temperature vents and diffuse flow communities have been mapped and monitored over the past 14 years. Concentric ellipses around the bull's eye encompass ridge segments at a range of scales, from the first-order segment bounded by the Siquieros and Clipperton transform faults to the fourth-order segment that includes the extent of the 1991 and 1992 volcanic eruptions. Five-year goals for the site include a working model of mantle flow and melt supply; detailed imaging of subseafloor structures and relationships to vent communities and chemistry; quantitative data about microbes and macrofauna and linkages with fluid flow, tectonics, and magmatism; quantification of the heat/chemical flux into the water column; and linkages and temporal variation in geological, chemical, and biological parameters.

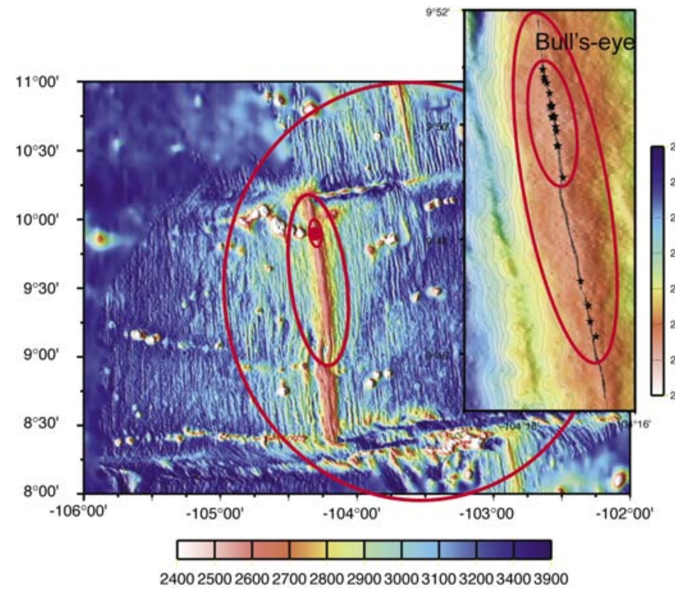


Fig. 1. *(above)* Bathymetry map of the EPR site. Red ellipses encompass different scales of ridge segmentation, which characterize the site. *(right)* Detailed bathymetry map of the site bull's eye (innermost ellipse) showing vent locations (black stars). Black line shows location of the axial summit trough.

Review of Funded Programs

Since the Ridge 2000 program began, eight field-based programs at the EPR ISS and two modeling studies with an EPR component have been funded. Many of the field programs went to sea in 2004 and/or have programs scheduled for 2005 (Table 1). The field studies fall into two main categories, which are closely linked to the five-year goals for the site:

1. *Imaging studies of the mantle-crustal heat source for the hydrothermal system and remote sensing for hydrothermal flow paths.* These studies include a magnetotelluric experiment targeting mantle and crustal resistivity structure (Constable et al.) and a three-dimensional multichannel seismic experiment (Mutter et al.) focused on the crustal magma body and upper crust within the site bull's eye region. Webb has recently been funded for a compliance study of crustal and mantle melt distribution beneath the contrasting ridge segments north and south of the Clipperton transform fault.

2. *Monitoring studies at the site bull's eye.* Monitoring programs include time-series sampling of vent fluid temperature and chemistry (Von Damm, Lutz et al.), and vent fauna (Lutz et al.) in three successive field seasons. Continuous monitoring of seismicity (Tolstoy/Waldhauser) throughout this period will permit characterization of the tectonic and magmatic events that occur and are likely drivers of change in hydrothermal characteristics. A geodetic study to monitor magma movements with a long-term deployment of pressure sensors along the ridge axis (Cormier et al.) has recently been funded, as well as a multiyear field program to study oceanographic and topographic influences on larval dispersal (Mullineaux et al.).

In addition to these experiments, a microbiological program focused on the role of microbes in weathering ocean crustal rocks is underway (Edwards/Bach). The modeling programs focus on the role of along-axis dike propagation in formation of axial topography (Buck) and on brine layers and off-axis recharge of the hydrothermal system (Wilcock). Descriptions of all funded programs at the EPR ISS can be found on the R2K website (http://www.ridge2000.org).

2004 Field Programs

Field programs at the EPR site in 2004 included several ongoing studies not funded under the R2K program but closely related in science goals. The field season began with a multiprogram cruise led by Schouten and colleagues that included dives for volcanological objectives, the deployment and testing of an array of in situ chemical sensors for use in monitoring vent fluids (Seyfried), and the deployment of sample collection plates by Edwards and Bach for their study of microbes and seafloor weathering. Also during this cruise, the final two of four permanent transponders for use during near-bottom operations were deployed.

Following the Schouten et al. program, Constable conducted his magnetotelluric and controlled source electromagnetic study from 9°30–50'N. The next cruises at the site were the time series fluid sampling program of Von Damm and biological study of Lutz and colleagues, both programs focused at the site bull's eye. During the Von Damm cruise, vent fluids were sampled and temperature probes from 13 high-temperature vent fields at 9°46'–9°51'N were recovered and redeployed. Rachel Haymon's student, Katie Inderbitzen, conducted a night program of off-axis coring for hydrothermal sediments.

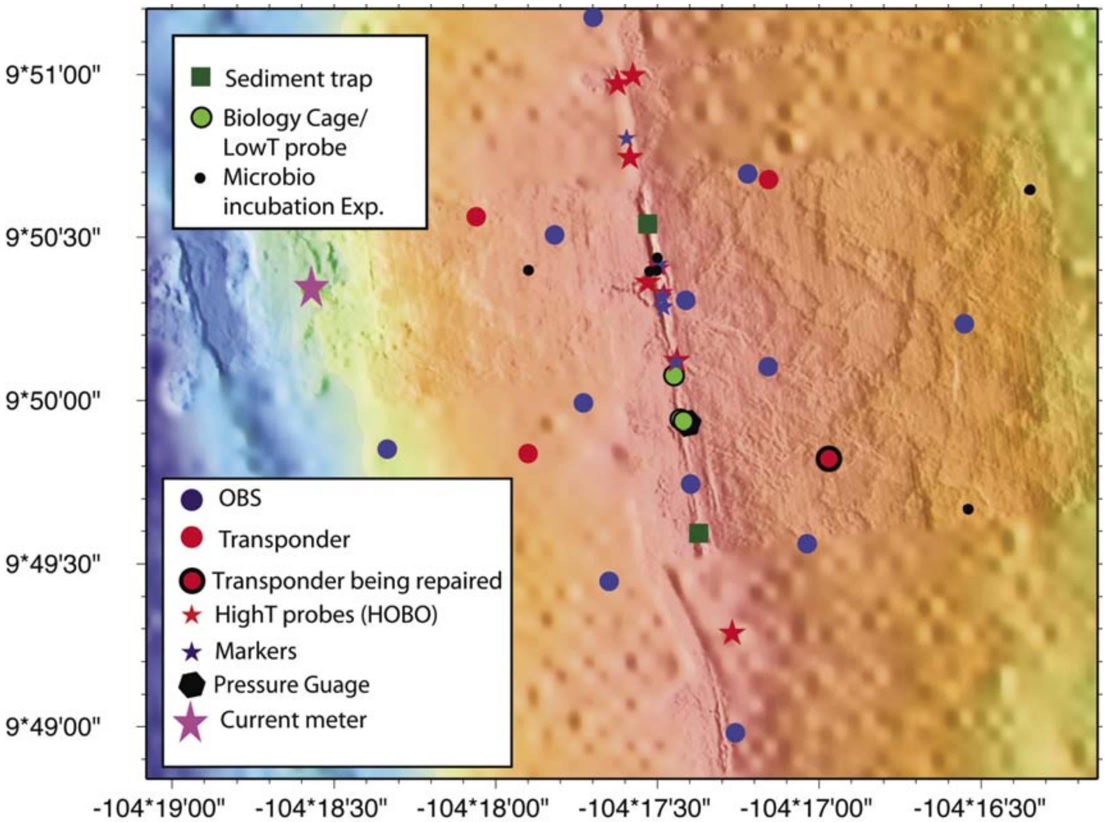


Fig. 2. Close-up of the bull's eye site showing locations of instruments and experiments deployed in the 2004 field season and currently on the seafloor (Jan. 2005). Bathymetry data include the ABE Imagenex ultrahigh-resolution (2 m) data from *Fornari et al.* [2004] merged with the 100 m surface ship multibeam data of *Cochran et al.* [1999].

During the Lutz et al. cruise, mussel exclusion cages were deployed for biological succession studies at three sites and photo imaging transects for time-series biological studies were conducted. OBSs deployed in Fall 2003 by Tolstoy/Waldhauser for monitoring microseismicity were recovered and redeployed. Edwards retrieved some of her sample collection plates during the Booksh Biocomplexity-funded cruise in November, and Lilley deployed a small in situ sensor to be recovered during the 2005 Lutz et al. program.

In November-December, Craig Cary and colleagues were at the site for the final of their three-cruise Biocomplexity-funded program focused on symbiotic interactions between bacteria and eukaryotic hosts (*Alvinella pompejana*).

Figure 2 summarizes the currently deployed instruments and experiments from the 2004 field season.

2005–2006 Field Program

In 2005, Lutz and colleagues will conduct the second cruise of their vent fauna and chemistry monitoring study, and Tolstoy/Waldhauser will retrieve and redeploy OBSs at the site. The Webb et al. compliance study is scheduled for late fall and will involve measurements at 50 sites on the axis and ridge flanks between 9°20'–10°20'N. During this cruise, Cormier will deploy 20 pressure sensors from 9°–10°N for her 4-year-long geodetic monitoring study. The Mutter et al. three-dimensional multichannel seismic study is expected to occur in early 2006 and will be conducted on the R/V *Langseth*. The first cruise of the Mullineaux et al. investigation of larval dispersal will occur in 2006 and will include measurements of larval positions and stages in the field, tracer release, and current meter measurements. The third cruise of the Lutz et al. biological monitoring program will also take place in 2006, and Von Damm will carry out the second cruise of her vent fluid monitoring study.

Table 1. 2005 Cruise schedule

PI (Program)	Dates	Ship	Purpose
Lutz et al/Tolstoy (R2K)	04/21/05-05/13/05	*Atlantis*, *Alvin*, 16 dives	Biology/OBS deploy recovery
Webb (NSF)	1/28/05-01/05/06	*Knorr*	Compliance
Cormier (R2K)			Geodetic

References

Cochran, J. R., D. J. Fornari, B. J. Coakley, R. Herr, and M. A. Tivey (1999), Continuous near-bottom gravity measurements made with a BGM-3 gravimeter in DSV *Alvin* on the East Pacific Rise crest near 9°30'N and 9°50'N, *J. Geophys. Res., 104,* 10841-10861.

Fornari, D., M. Tivey, H. Schouten, M. Perfit, D. Yoerger, A. Bradley, M. Edwards, R. Haymon, D. Scheirer, K. Von Damm, T. Shank, and A. Soule (2004), Submarine lava flow emplacement at the East Pacific Rise 9°50'N: Implications for uppermost ocean crust stratigraphy and hydrothermal fluid circulation, in *Mid-Ocean Ridges: Hydrothermal Interactions Between Lithosphere and Oceans, Geophys. Monogr. Ser.,* vol. 148, edited by C. R. German, J. Lin, and L. M. Parson, pp. 187-217, AGU, Washington, D.C.

Status Report on the Lau Basin ISS

Doug Weins *(Washington U in St. Louis), Oversight Committee Chair*
Geoff Wheat *(U Alaska, Fairbanks), Site Coordinator*
Fernando Martinez, *Lau ISS Principal Investigator*
Charlie Langmuir, *Lau ISS Principal Investigator*

Background

Study of a back-arc basin spreading center represents a new direction for the Ridge 2000 program. Because the geodynamic setting, petrology, chemistry, and biota are different from the EPR and JdFR, the East Lau Spreading Center (ELSC) provides distinct contrasts to the other IS sites. The ELSC, located in the western Pacific near Tonga, is a 390 km-long first-order ridge segment that displays a broad range of effects of the back-arc environment. Its southern end, only 40 km from the Tonga arc volcanic front, is propagating southward into a back-arc rift. Its northern end, 100 km from the volcanic front, terminates at a large, non-transform offset.

The ELSC undergoes substantial and systematic changes in primary parameters affecting crustal accretion, including spreading rate and mantle source composition. Consequently, the spreading center displays large changes along its length in lava chemistry, axial depth and morphology, melt lens characteristics, and crustal thickness and structure. A focus of Ridge 2000 work at the ELSC is to understand how changes in these forcing functions affect crustal accretion, hydrothermal venting, and faunal composition and abundance.

The 2004 field programs were highly successful: in conjunction with detailed mapping, plume sampling, and rock sampling efforts, numerous potential focus areas with hydrothermal activity were identified and imaged. Three additional cruises between April and July 2005 will conduct interdisciplinary hydrothermal and biological investigations using *Jason II.*

Cruise 1: Investigating the interrelationships between crustal structure, volcanism, and hydrothermal activity along the East Lau Spreading Center (April-May 2004)

PIs: F. Martinez and B. Taylor, University of Hawaii; J. Resing and E. Baker, University of Washington and PMEL/NOAA

Nested shipboard multibeam and deep-towed sonar surveys were conducted in April-May 2004 along the ELSC to map the spreading axis in detail. Mapping operations collected overlapping coverage using:

- R/V *Kilo Moana* hull-mounted Simrad EM120 multibeam/side-scan system for broadest coverage.
- IMI-30 side-scan sonar towed at 500 m above bottom. A 2-km swath of imagery and slightly narrower bathymetry was achieved on this first operational use of the instrument.

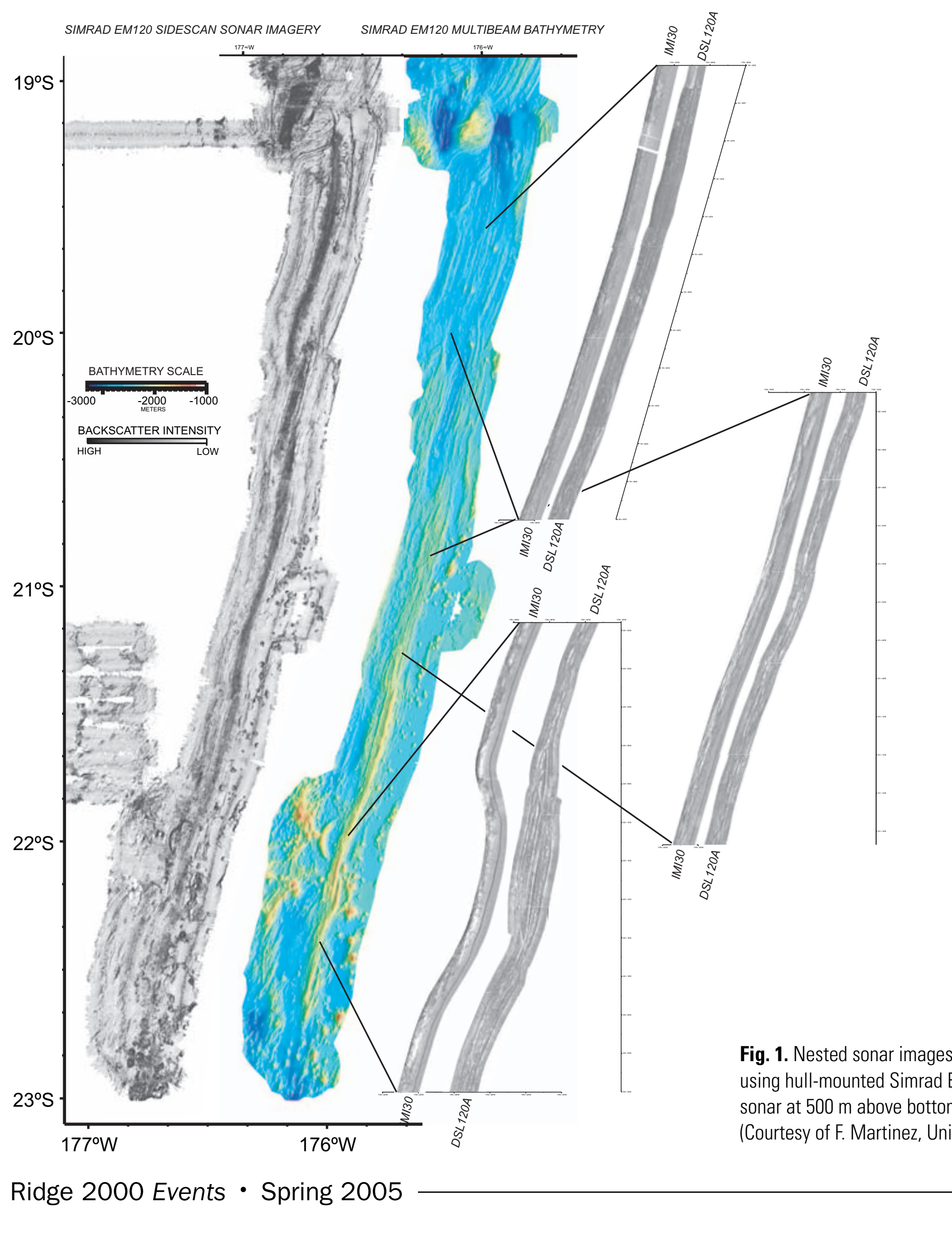


Fig. 1. Nested sonar images of seafloor at East Lau Spreading Center were produced using hull-mounted Simrad EM120 multibeam and sidescan sonar, IMI-30 sidescan sonar at 500 m above bottom, and DSL-120A sidescan sonar at 100 m above bottom. (Courtesy of F. Martinez, University of Hawaii)

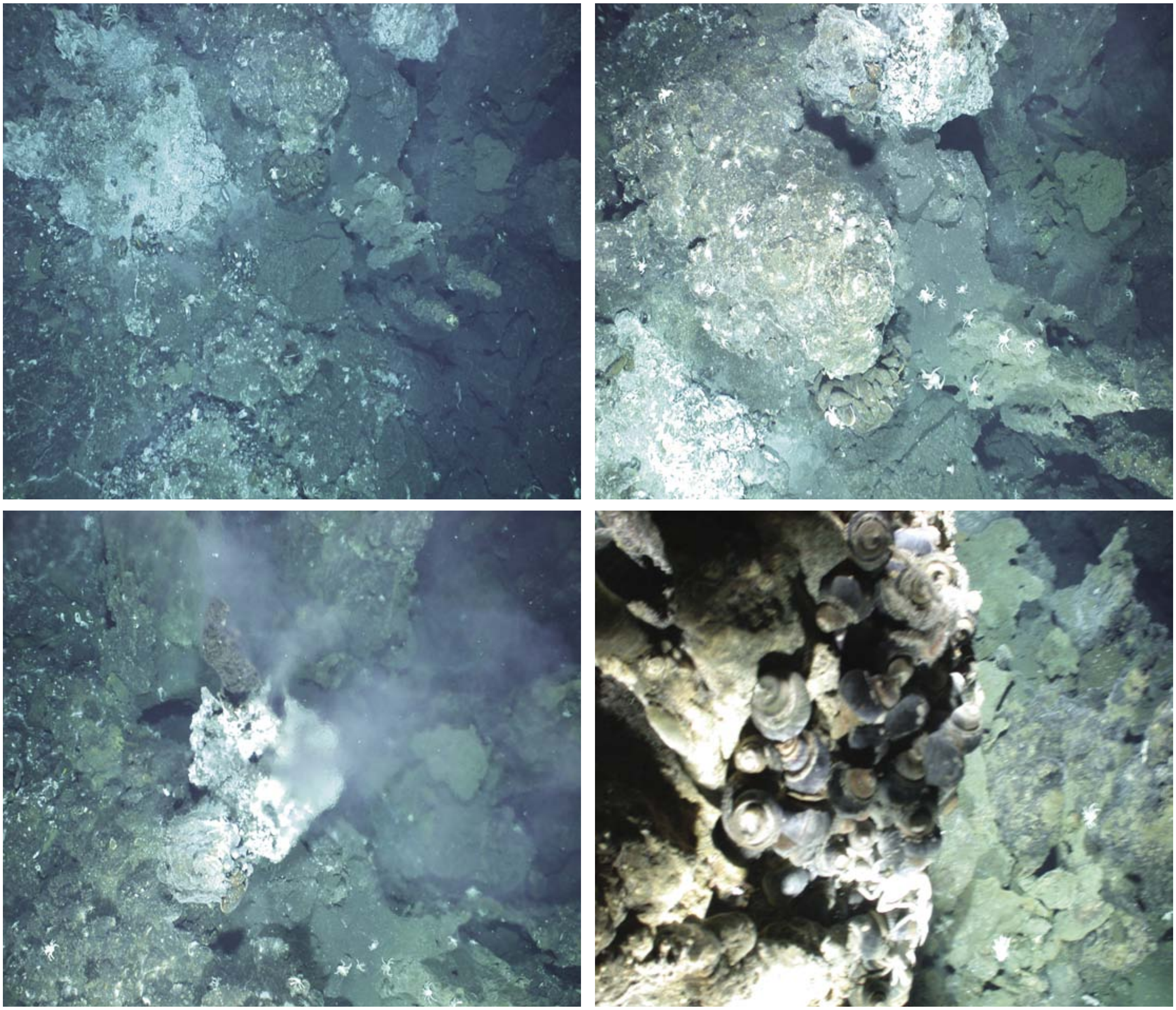


Fig. 2. Seafloor images taken during Lau ISS cruise 2 (PI: C. Langmuir) with "TowCam," a digital deep-sea towed camera system that can snap about 1800 pictures per run, or about one every 10 seconds. TowCam also carries equipment for water sampling and rock coring. (Courtesy of T. Shank, Woods Hole Oceanographic Institution.)

- DSL-120A side-scan sonar towed at 100 m above bottom for a 1 km-swath of imagery and slightly narrower bathymetry.

The nested survey methodology provided the highest resolution but narrowest width of coverage along the neovolcanic axis, with decreasing resolution outward as width of imagery increased. The methodology also allowed cross-validation of instruments. See Figure 1.

Concurrent surveys of the water column continuously along the axis using MAPR/Chemical Scanner and CTD/rosette tow-yos and vertical casts found evidence of abundant hydrothermal activity all along the spreading center and especially toward the north even though magmatic robustness decreases to the north.

Cruise 2: Integrated hydrothermal and petrological studies of the East Lau Spreading Center (Sept-Oct, 2004)

PIs: C. Langmuir, Harvard University; H. Edmonds, University of Texas; P. Michael, University of Tulsa; D. Yoerger, A. Bradley, and T. Shank, Woods Hole Oceanographic Institution; S. Goldstein, Columbia Lamont-Doherty Earth Observatory; and D. Graham, Oregon State University

This cruise combined a three-phase approach using an automated underwater vehicle (ABE, the Autonomous Benthic Explorer) with detailed rock sampling during ABE deployments. Working from the water column data identified during cruise 1, six sites were selected for more intensive search for hydrothermal sites. CTD/Rosettes were followed by ABE dives in three phases—first to sample the water column, then to identify the buoyant stems of hydrothermal plumes and generate high-resolution maps, and finally to make photo-mosaics to identify specific hydrothermal sites and their associated biota. This approach led to the discovery of three new vent sites, named Kilo Moana (see Cover Figure), TowCam, and ABE Vent Fields, in September–October 2004. These three new vent sites cover the desired range of latitude, depths, and rock composition along the ELSC and Valu Fa. The team also collaborated with the Japanese on the discovery of a fourth field. ABE technology proved its worth among the complimentary tools used to search and locate hydrothermal vents. The rock recoveries also have led to the ELSC being the most intensively sampled back-arc basin in the world. See Figure 2.

LAUB-FLEX — Deep circulation and dispersal in the Lau Basin using floats

PIs: A. Thurnherr and K. Spear, Florida State University

Observation of deep-ocean currents is ongoing via APEX floats deployed during cruise 1 and PROVOR floats released during cruise 2. The floats drift at a constant depth of 1730 m, rise to the surface at 3- and 4-week intervals to transmit their data via satellite, and return to their drifting depth for continued operation. The floats are providing almost real-time data, which can be viewed at www.ldeo.columbia.edu/~ant/LAUB-FLEX/. After only a few cycles, float displacements indicate persistent northward flow along the East Lau Spreading Center. Drift velocities observed so far are as high as 4 cm/s, about 10x faster than expected. In addition to providing background data that are required to interpret hydrothermal-plume dispersal observations and biogeographic patterns, the float trajectories will also provide the first measurements of deep-ocean circulation in the Lau Basin, yield new insights into processes acting in confined basins and near rough topography, and provide needed data for improving numerical circulation models.

Cruise 3: April 7–May 10, 2005, Sampling and initial characterization of hydrothermal fluids, deposits, microfauna, and megafauna at vent fields along the Eastern Lau Spreading Center

PIs: M. Tivey and J. Seewald, Woods Hole Oceanographic Institution; S. Kim, Moss Landing Marine Laboratories; M. Mottl, University of Hawaii; and A. Reysenbach, Portland State University

The ROV *Jason II* was launched at the new hydrothermal vent fields identified during the previous cruises to map structures, types of venting, and animal communities, to sample and analyze hydrothermal fluids and sulfide structures, to sample and identify vent animals and microbes, and to sample larvae and plankton in near-bottom waters.

Future Plans

Cruises 4 and 5 will more fully characterize the chemistry and fauna of the vent fields discovered on cruises 1 and 2. All of this data will feed into a community decision on where to locate the Lau Basin ISS bull's eye. The "bull's eye" designates the vent field where Ridge 2000 studies conducted at vent-field scale and smaller will be co-located to maximize collaboration and integration of disciplines. Studies requiring larger spatial scales will be nested around this designated focal area and expand outward in elliptical bands that encompass the area required for the specific research. Community participation will be solicited for a decision on the bull's eye.

Cruise 4: May 15–June 3, 2005, Multispecies phylogeography of Lau/Fiji Basin vent fauna

PI: R. Vrijenhoek, Monterey Bay Aquarium Research Institute

Although not funded under Ridge 2000, this NSF-sponsored research, with 12 proposed dives in the Lau and Fiji Basins, seeks to understand evolutionary relationships among Pacific vent fauna. Between 3 and 6 dives are planned for the ELSC at sites identified by the previous cruises. By studying multispecies phylogeography via DNA sequencing and gene trees, the distribution of genetic diversity in natural populations can be explored and larval dispersal can be better understood.

Biogeography and community structure in mussel beds at Pacific hydrothermal vents

PI: C. Van Dover, The College of William and Mary

With emphasis on mussel communities, this work will expand research on hydrothermal vent and cold seep community structures and biogeographic analyses of organisms to include vents in back-arc basins. These analyses will help reveal evolutionary alliances of vent faunas in back-arc basins with faunas at mid-ocean ridge sites within the Pacific basin. Potential barriers or conduits to dispersal, particularly the degree of isolation within a back-arc basin system, will be explored.

Cruise 5: June 8–June 30, 2005 Site evaluations and background studies of interactions among fluid chemistry, physiology, and community ecology

PIs: J. Childress, University of California–Santa Barbara; S. Kim, Moss Landing Marine Laboratories; C. Fisher and S. Hourdez, Pennsylvania State University; and G. Luther, University of Delaware

Continuing with *Jason II* at the previously identified hydrothermal vent fields, this group will conduct detailed mapping of animal community distribution and composition, perform in situ analyses of diffuse hydrothermal fluids around animals, deploy thermistor arrays, make quantitative collections for community ecology analyses, and additional collections of specimens for shipboard studies of live animals. A follow-up cruise for this project is planned for 2006.

Education and Outreach Program

The Ridge 2000 Program office embarked on a major outreach project to bring the excitement of ridge research to a general audience. The Lau Basin Integrated Studies Site was selected for this effort because it allows the public to participate vicariously in the thrill of discover in a relatively unexplored area. Writer Kristen Kusek accompanied the Langmuir cruise to produce human interest-type articles and a photo journal of shipboard activities for a dedicated website for the cruise. That website has been reconfigured for a more general ridge website focused on a public audience: http://www.venturedeepocean.org. Check it out and let us know what you think—we would appreciate your feedback.

Status Report on Time Critical Studies

TCS Oversight Committee
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The Time Critical Studies (TCS) theme of Ridge 2000 focuses on observations of the immediate geochemical and geobiological consequences of magmatic and tectonic events along the global mid-ocean ridge system.

TCS funding is centered on the Juan de Fuca and Gorda Ridges because these ridges are within range of the Northeast Pacific Sound Surveillance System (SOSUS) operated by the U.S. Navy and research ships are often available in this area on short notice. NOAA/PMEL's T-Phase Monitoring Project accesses SOSUS in real-time and provides the TCS community with detection of seismicity associated with eruptive or tectonic activity along these two ridges. Detection of earthquake swarms, coupled to pre-event staging of equipment and supplies at the Pacific Marine Environmental Laboratory (PMEL), allows directed and increasingly well-organized field responses to the event site (Table 1).

Major rapid and follow-up response cruises have been successfully mounted to 1993 CoAxial, 1996 and 2001 Gorda Ridge, 1998 Axial Volcano, and 2001 Middle Valley magmatic episodes, and the most recent cruise in February–March 2005 to Endeavour (described below). The logistical approach required to study these events has been greatly facilitated by the RIDGE and Ridge 2000 programs and collaboration between university, NOAA, and Canadian investigators. National Science Foundation and NOAA/PMEL VENTS funding was key to these successful rapid responses.

TCS studies of these events not only have significantly influenced ideas on the nature of crustal accretion, but also have provided evidence of a biomass reservoir and increased appreciation of "Event Plumes" in the water column. Rapid response studies have provided preliminary documentation of a previously unrecognized biomass reservoir that lives below the seafloor and is swept out during cataclysmic events. In addition, the community now has a greater understanding of the formation and thermal, chemical, and biogeochemical implications of the "Event Plumes" commonly associated with seafloor magmatic events.

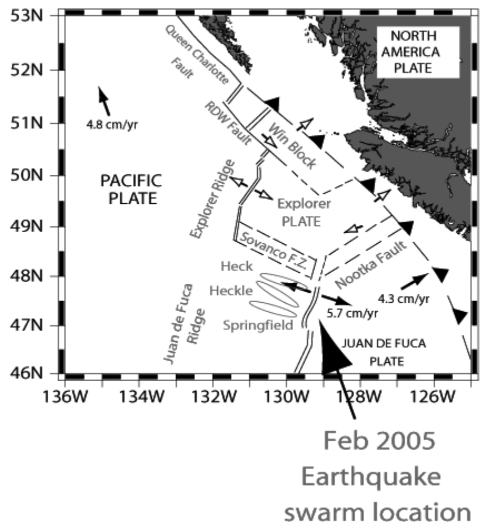

Fig. 1. TCS rapid response teams were on station just 6 days following notification of the onset of earthquake swarms on the Endeavour Segment, depicted in the cartoon. Event counts were as high is 50 to 70 per hour, which is similar in scale to seafloor spreading events, but chemical data showed no water column signal. (Image courtesy of Bob Dziak, NOAA/OSU Vents Program.)

Table 1. Currently funded core studies for Northeast Pacific TCS

Parameter Method	Responsible	Institution
Event Detection	SOSUS	PMEL
Plume Mapping	XBTs[1], CTD[1]	U Hawaii[2], PMEL
Plume Geochronology	Isotopic half-lives[1]	RSMAS[2]
Particle Dynamics	Particle size/conc. [1]	UH[2], PMEL
Geochemistry	Dissolved/particulate chemistry[1]	UW[2], UH[2], PMEL
Geomicrobiology	Microbially mediated chemistry[1]	UH[2], UW[2]
Microbial Diversity	Genetic/Microscopic	OSU[2], UH[2]
Event Plume Tagging	RAFOS floats[1]	SFSU[2], PMEL
Seafloor Imaging	Digital camera sled[1]	WHOI[2], PMEL

[1]All or part stored at PMEL; [2]NSF-R2K funded

Recent Detected Events on the JdFR

2005. On Sunday morning 27 February at 0031Z, the SOSUS system detected the start of an intense earthquake swarm on the Endeavour segment of the northern Juan de Fuca Ridge (Figure 1). More than 3,740 earthquakes were detected over a 5.5-day period. Event counts were as high as 50-70 per hour, which is similar in scale to seafloor spreading events at Middle Valley in 2001 and Endeavour in 1999. The preliminary location of the swarm's epicenters was 48°14.5'N, 128°57.6'W, which is ~36 km north-northeast of the Main Endeavour vent field and a few kilometers east of the intersection of the Heck Seamounts with the JdFR axis. The sequence has also produced three large earthquakes (M_w 4.5, 4.8, 4.9), which have been detected by the National Earthquake Information Center (NEIC), University of Washington (UW), Pacific Northwest Seismograph Network (PNSN). The February/March seismic swarm also sustained an elevated, nearly constant rate of similar magnitude earthquakes for several days, consistent with magma intrusion and in contrast to the "mainshock-aftershock" sequence characteristic of tectonic events. SeaMarcII sidescan data [*Davis and Currie,* 1993] clearly shows evidence that the northern extension of the Endeavour segment within the overlap zone contains recent lava flows. The earthquake locations from this swarm are not precise enough to distinguish whether the events were located along the volcanic segment's limbs or within the tectonic overlap zone. It appeared possible, therefore, that a dike could have been injected from the axial high of the Endeavour segment into the overlap zone, resulting in the earthquake swarm. Recent sidescan seismic studies revealed a likely axial magma chamber reflector north of the main Endeavour vent fields, at the southern limit of the February/March seismic swarm. All this evidence, combined with the proximity of the seismic events to the Endeavour Integrated Studies Site (ISS), contributed to our decision to respond rapidly to this event.

This episode of event remote detection and rapid response demonstrated a remarkable degree of cooperation and dedication among university and government scientists and their respective infrastructures, funding agencies and their program managers, UNOLS and university ship operators, and a host of other important contributors to this effort. The Ridge 2000 community was informed of the seismic swarm on Monday, February 28. Animated discussion concerning the nature and implications of this event were started immediately. Response personnel from outside Seattle were en route by Thursday, loaded the ship on Friday, and sailed from the University of Washington dock at 0900 hr Saturday morning. We were on station by Sunday morning, just 6 days after notification of the seismic swarm, a task that usually requires a lead time of over a year. The detection and response team gratefully acknowledges the assistance of the very many people who got us on our way. We want to especially thank Dave Epp of the NSF-Ridge 2000 Program and Steve Hammond of NOAA-Ocean Exploration for funding the response cruise.

Results from the response cruise indicate that it is unlikely that the February/March 2005 earthquake swarm (Figure 2) induced any corresponding expression at the seafloor (e.g., eruption of a lava flow) or in the water column (e.g., formation of new hydrothermal venting, either chronic or event plumes). The in situ and shipboard physical and chemical data from the 3 long tow-yo casts and 7 vertical casts revealed no water column signal that can be clearly associated with the recent earthquake swarm, whether magmatic or tectonic. Initial calculations of methane to hydrogen ratios from the MEF, Mothra, High Rise, or Salty Dawg are comparable to historic (2003) values from vent fluids. No evidence of any temperature or optical anomalies was seen in the near-bottom camera tow data (CTD or MAPR) overlying an axial magma chamber reflector, close to the region of the February/March swarm. Camera images of the seafloor revealed no fresh basalt; rather, the entire camera tow track was moderately to heavily sediment-covered lavas. Finally, we searched for evidence of new lava flows in the earthquake area by comparing before and after high-resolution multibeam bathymetry data. No bathymetric anomalies were detected. At this time the probable explanation for the failure to discover significant event-related hydrothermal discharge is that the earthquake swarm likely reflected an intrusive magmatic event that did not reach sufficiently shallow crustal depths to lead to extrusion (eruptive flows) or stimulate venting at new or existing vent fields as discernable via surface ship sampling.

This February/March event detection and response experience has stimulated a constructive exchange of ideas and questions regarding the interpretation of available relevant seismological and geological data and the criteria used in evaluating the appropriate response to this event. Much of this exchange has been posted on the Ridge 2000 Program's Time Critical Studies website. A paper is planned to summarize the geological, seismological and other geophysical data available at the time of all past SOSUS directed response cruises (1993 Co-Axial; 1996 North Gorda Ridge; 1998 Axial Volcano; 2001 Jackson Segment, Gorda Ridge; 2001 Middle Valley; 2005 Endeavour) as well as events detected but not responded to (e.g., 1999 Endeavour). The emphasis of this paper will be the evaluation of data available during the brief period following initial detection of onset of seismic swarm and the decision whether to launch a rapid response. It may also be appropriate to hold a community workshop to discuss response criteria, data interpretation, and other TCS issues in the near future.

Table 2. Event Response Contacts

Contact	Affiliation	E-mail
R2K Office		Ridge2000@psu.edu
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Marv Lilley	TCS/NSF-PI	lilley@u.washington.edu
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Dave Kadko	NSF-PI	dkadko@rsmas.miami.edu
Toby Garfield	NSF-PI	garfield@sfsu.edu
Ed Baker	PMEL-PI	edward.baker@noaa.gov
Joe Resing	PMEL-PI	joseph.resing@noaa.gov
Bob Embley	PMEL-PI	robert.embley@noaa.gov
John Lupton	PMEL-PI	john.lupton@noaa.gov
Dan Fornari	NSF-PI	dfornari@whoi.edu

TCS: TCS Oversight Committee; NSF-PI: R2K funded PI; PMEL-PI: PMEL funded PI

2004. Two events were reported to the Ridge 2000 community in the final months of 2004. First, on November 2, an exceptionally large (M_w 6.7) strike-slip earthquake occurred along the southeastern Explorer plate. Several dozen aftershocks, six of which had magnitudes between 4.5 and 5.0, occurred within 10 hours. Details of the earthquake sequence can be found on the following websites:

http://earthquake.usgs.gov/eqinthenews/2004/usqial/

http://www.pgc.nrcan.gc.ca/seismo/mstrec/local/20041102-locmap.htm

Second, the community was informed of a small swarm of 34 earthquakes that SOSUS detected at the Endeavour segment of Juan de Fuca Ridge (JdFR) over a four-hour period beginning at 0218Z on Dec. 2. The earthquakes were centered at 48° 12.3'N, 129° 4.7'W, which is the intersection of the easternmost Heck seamounts with the southern tip of West Valley, about 20 to 25 km north-northwest of the Main Endeavour Vent Field. Small, short-duration earthquake swarms at this location on the Endeavour segment have been common over the past 12 years.

Neither the November nor the December events were considered significant enough for the TCS community to launch a rapid response; however, the Oversight Committee announced the events via Ridge 2000 email to the community. The Oversight Committee views these announcements as providing a long-term, near real-time historic perspective of earthquake activity in the NE Pacific for all interested parties. The announcements also alerted all researchers who may have in situ instruments on the JdFR to check for fluctuations/changes in their data around these times.

TCS PIs Ready To Respond

PIs from 6 NSF-Ridge 2000-supported institutions and the NOAA/PMEL VENTS program are currently funded to maintain readiness to

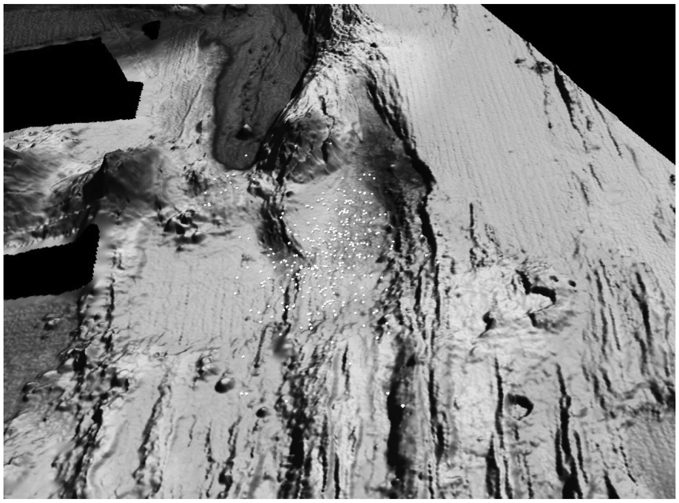


Fig. 2. Oblique 3D view of the February-March 2005 earthquake swarm area on the Endeavour Segment, Juan de Fuca Ridge. SOSUS detected 3742 quakes in 5.5 days, but physical and chemical results from the response cruise showed no corresponding expression on the seafloor. Epicenters are white dots. (Image courtesy of Bob Dziak, NOAA/OSU Vents Program. See color image on page 1.)

rapidly respond to major magmatic and tectonic events in the Northeast Pacific (Juan de Fuca and Gorda Ridges). Funded core studies are listed in Tables 1 and 2. Most response equipment and supplies are now stored at PMEL (Seattle) for rapid deployment. In addition, a PI at the University of Hawaii has developed techniques to date young lavas, thereby verifying eruptive events and corroborating hydrophone data (see K. Rubin, this issue). For events occurring beyond the range of the hydrophone system, lava flow chronology can be essential.

Proposals related to TCS are encouraged (see TCS Funding Opportunities). Especially note the growing close link between TCS and in situ instrumentation at Ridge 2000 Integrated Studies Sites (ISSs).

Revisions to Event Announcements

The TCS subcommittee is working to identify a subset of Ridge 2000 researchers who are interested in receiving more detailed information than is commonly provided to the whole community about the real-time detection of moderate-sized earthquake swarms and tectonic events on the JdFR from the SOSUS hydrophone array. The committee's goal is to provide a long-term, historic perspective of earthquake activity on the JdFR for all interested parties, and to alert all researchers who may have in situ instruments on the JdFR to check for fluctuations/changes in their data. By identifying a subset of interested researchers, we hope to avoid inundating the email IN boxes of the entire community, many of whom may be less interested in the detailed seismic reports. The whole Ridge 2000 community will still receive email announcements of all major events.

An important part of TCS is continued interaction with the Integrated Studies Sites in terms of focusing attention on the real-time detection and recording of events and their associated physical/chemical/biological effects. In an attempt to quantify estimates of swarm size and keep the workload to a manageable level, henceforth, committee members will send out announcements only

- if an earthquake swarm exceeds 10% of the variance in the long-term (13 yr) JdFR earthquake database (swarms can vary from 40 to >150 earthquakes per month, depending on the ridge or transform segment)
- if the swarm is close to an ISS or well-instrumented site (i.e., Axial Volcano)
- if the hydrophones detect exceptionally large tectonic events (e.g., the 11/02/04 M_w6.7 Explorer plate earthquake)

The committee also will continue to announce past earthquake swarms (1-2 yr) recorded on hydrophone arrays along the East Pacific Rise and the Mid-Atlantic Ridge to support potential delayed response efforts. As a recent example of the latter, several large earthquakes were detected from the Wilkes Transform (~9°S, 109°W) and were accompanied by low-frequency, continuous tremor-like energy suggestive of a magmatic component to the earthquake swarm. The earthquakes and tremor, however, occurred from 19 to 27 September 2002, and were discovered only recently because the hydrophones are recovered on a 2-year cycle.

Finally, the committee is planning to compile and continually update a list of "events" with date, location, and seismic characteristics. This list will be available to the community through the website, www.Ridge2000.org.

If you are interested in receiving the more frequent announcements of swarm activity, please respond to this email address: Ridge2000@psu.edu. Simply indicate that you wish to be on the TCS – Frequent Announcements email listing.

TCS Funding Opportunities

Rapid shore-to-event-site response is a central aspect of TCS. Proposals to enhance the event detection and response effort are welcome at any Ridge 2000 target date (Feb. 15 and Aug. 15). The Ridge 2000 program recognizes that even the most rapid ship response will miss the earliest subsurface and water column expressions of magmatic events. Consequently, Ridge 2000 also seeks proposals to develop alternate ultra-rapid response methods including air-droppable monitoring devices and in situ sensors. Coordination with ISS instrument deployments and increased field presence, as well as with the proposed cabled and moored Ocean Observatories at ISSs, is strongly encouraged. Contact information for the Ridge 2000 office, Time Critical Studies Oversight Committee members, and the TCS PIs currently funded through NSF-Ridge 2000 are listed in Table 2.

References

Davis, E. E., and R. G. Currie (1993), Geophysical observations of the northern Juan de Fuca Ridge system: Lessons in sea-floor spreading, *Can. J. Earth Sci.*, *30*(2), 278-300.

Endeavour ISS *continued from page 8*

In September 2005, the second year of Keck seismic data will be recovered using the ROV *Jason 2* onboard the R/V *Thomas G. Thompson.* In addition to allowing the Keck team to continue to monitor local seismicity on the Endeavour, the data from the three regionally distributed broadband sensors will facilitate a detailed analysis of seismicity on the Explorer Plate, including the magnitude 6.6 earthquake on November 2, 2004, and its aftershock, as well as the February–March 2005 earthquake swarm. The small exploratory local network at the Nootka site will provide information on the distribution of small earthquakes beneath seep sites.

Keck In Situ Geochemical, Microbiological, and Fluid Sampling

The 1999 injection of melt and associated earthquake swarms beneath Endeavour significantly changed the temperatures and chemistry of vent effluent, particularly within the Main Endeavour Field [*Davis et al.,* 2001; *Lilley et al.,* 2003; *Seewald et al.,* 2003; *Seyfried et al.,* 2003; *Bohnenstiehl et al.,* 2004]. Although sampling was not done until several months following this event, very significant increases in volatiles such as CO_2, He, and H_2 were associated with injection (*Lilley et al.,* 2003). Follow-on studies in 2000 showed that vent fluid temperatures increased by as much as 15°C, carbon isotopic values of CO_2 were reset to some of the most primitive values measured for mid-ocean ridges [*Proskurowski et al.,* 2004], new chimneys developed, vigorous boiling and condensation affected many of the chimneys, and ejection of flocculent material into the water column dramatically increased [*Kelley et al.,* 2002]. Based on follow-on analyses, it was estimated that as much CO_2 was released during this single event as that over an entire year of venting [*Lilley et al.,* 2003]. In the few years following this event, volatile concentrations have returned to pre-event values, and the emission of fresh fluids, which was a hallmark of the MEF system, has disappeared with most chimneys venting fluids of near seawater salinity. Concurrent changes include significant drops in temperature, waning of venting in some sulfide complexes (e.g., Cathedral), and a substantial increase in macrofaunal growth on some chimneys.

With the recognition that (1) there are dramatic changes in temperature and chemistry that occur over very short time periods associated with magmatic and tectonic events at Endeavour and (2) the system has continued to change for several years, four prototype temperature-resistivity-hydrogen (RTH) probes were deployed in the orifices of active smokers in 2004 (Figure 2D). Three of these are in the MEF (Sully, Bastille, and Hulk), and one in the Faulty Towers Complex in the Mothra Hydrothermal field (Hot Harold)(Figure 1). The RTH instruments use a four-electrode system to measure fluid resistivity. The H_2 sensor system is based on a gold/palladium membrane that is permeable only to H_2. By allowing H_2 to cross the membrane where its partial pressure in a fixed volume behind the membrane equilibrates with that of the fluid, a measure of internal pressure can be equated with H_2 concentration in the fluid. Temperature is measured with a type K thermocouple. Because chloride is by far the predominant anion in hydrothermal fluid, resistivity serves as a useful proxy for chloride concentration. Temperature, resistivity (an analogue for chlorinity), and H_2 were focused on because temperature and chlorinity control metal complexing within the fluids, and boiling and phase separation processes control gas concentrations. In addition, hydrogen concentrations provide information about fracturing processes deep within the crust, and hydrogen is a critical energy source for microbial communities. These parameters are also important to monitor in the context of chemical changes associated with seismic activity where major flux variations can occur on short time scales. Temperature-resistivity probes were first deployed at Endeavour in 2000 [*Larson et al.,* 2005], and new additions to these instruments include H_2 capabilities and inductively coupled links (thanks to Al Bradley at WHOI and funding through NSF) that allow two-way communication with the instruments from ROVs or submersibles without recovering the instruments. Data can be downloaded in place and data acquisition rates can be modified. In addition, a pressure sensor was deployed in MEF to monitor tidal oscillations (Figure 1). These instruments will be recovered in September 2005 and redeployed for another yearlong experiment.

A major component of the Keck program (as well as Ridge 2000) is to investigate the link between seismic activity, hydrothermal flow, and microbial communities. In 2003, two Remote Access Samplers (RAS) and one Phyto-Plankton Sampler (PPS) manufactured by McLane Research Laboratories were deployed to sample hydrothermal fluids and particulate DNA (Figure 2B) [*Butterfield et al.,* 2004]. The RAS collects 48 water samples (up to 500 ml per sample), and each sample is filtered to remove particulate material entrained with the sample. One PPS and RAS were combined on a single mooring with one intake line within the MEF at a diffuse flow site on the south side of Hulk (Figure 1). This system was designed to sample chemistry and microbiological communities from the same diffuse site. A second RAS was deployed on a sulfide mound at the Clam Bed field south of High Rise. All three of these instruments were recovered in 2004.

The RAS and PPS deployment at Hulk worked extremely well with successful sampling occurring over the 41-week duration of the experiment. Figure 3B shows an example of some of the fluid chemistry obtained during this experiment. Preserved DNA was frozen and is awaiting analysis. The Clam Bed experiment showed a great deal of variability, but was cut short at 23 weeks when a worm worked its way into the intake line and caused a complete blockage. Twenty-two samples were recovered in the first time-series measurements for fluids at Clam Bed. Significant growth of sulfide and tubeworms on the active Clam Bed mound completely hid the temperature recorder such that it could not be recovered. Chemical data from both of the time-series sampling locations will be related to temporal and spatial information on seismicity recorded by the seismic network.

For the 2004-5 period, the RAS and PPS were redeployed on the south side of Hulk in diffuse flow. A current meter was also added to the experiment to investigate local current variations coupled to changes in fluid chemistry. These data will also be correlated to pressure data recorded near Grotto to examine the effects of tidal pumping. A second PPS was deployed in the Cuchalainn Complex in the southern portion of the Mothra Hydrothermal Field (Figure 4A). Vents within Mothra have salty effluent and this experiment was designed to look at both temporal and spatial variation of fluid chemistry along axis. All these instruments will be recovered and redeployed in September 2005. In concert, these instruments will allow monitoring of the chemical and microbial composition of the vent effluents, provide samples that will allow determination of changes that might occur over the year, and relate the changes to seismic activity detected by the seismometer array. There have been very few collections of vent fluid samples on this time scale, and none in association with an array of seismometers.

Keck Microbial-Geochemical Linkages

As part of the Keck collaboration, MBARI contributed significant resources and 10 dives with the ROV *Tiburon* on the R/V *Western Flyer*. This project focused on examining the microbiological diversity in a variety of venting environments at Endeavour. During these dives, water, sediment, sulfide, and basalt samples were systematically and extensively collected. When possible, samples were collected concomitantly for geochemical analyses. For example, researchers used both gas-tight and syringe samplers to collect approximately 30 water samples along a transect that crossed the axis of the field. Using a newly designed filtration apparatus, microbiota were collected from fluid samples for laboratory analysis without altering or interrupting the analytical stream. These co-registered data are providing insight into the extent of chemoautotrophic potential within and outside the vent field. In particular, there is evidence for substantial anaerobic chemoautotrophic microbial populations in seawater samples that were primarily oceanic in origin. Ongoing analyses of these samples are focused on determining if these microbes were metabolically active at the time of collection. This filtration approach can be used by future investigators to collect microbiological samples from the variety of major samplers commonly used to collect fluids for chemical analyses.

Sediment and sulfide talus were collected to compare the distribution and abundance of the major microbial communities found on sulfides. To that end, quantitative PCR (Polymerase chain reaction) methods were developed to map the density of the major groups. These analyses will help determine if the dominant microbiota can survive in the sulfide talus without significant influence from vent effluent. Preliminary data indicate that microaerophilic sulfide oxidizers, which are dominant on sulfides, can flourish in the talus as well. Within talus-rich environments, these organisms may flourish because of their ability to catabolize elemental sulfur or polysulfides rather than more reduced sulfur compounds.

Sulfide samples were also collected along a vertical and horizontal gradient to examine the isotopic composition of microbiological biomarkers (such as lipids and nucleic acids) with changes in environmental conditions. These samples and analyses are being used to explore the flow of carbon and nitrogen through microbial communities at vents. Preliminary data suggest that vent effluent-derived carbon can be easily detected up to 3 m away from an active vent in microbiological biomarkers (lipid 13-C isotopic composition). These results may reflect the growth dynamics of microbial communities in situ (i.e., population growth is ephemeral and occurs primarily when communities are exposed to vent effluents). However, many key aspects of the microbiota, in particular their role in governing biogeochemical cycles, are difficult to examine in vitro and remain poorly characterized.

Understanding the In Situ Conditions Under Which Microorganisms Survive, Thrive, and Expire

Through funding from the NSF, the University of Washington, and Keck, new in situ sensor packages were deployed in the Mothra Hydrothermal Field in 2003 and 2004. The sensor packages were designed to quantify the spatial and temporal variation of environmental parameters and associated microbial communities within the walls of active black smoker systems. The proof-of-concept prototype packages include titanium-sheathed, 53 cm long, 3-chambered probes that allow in situ continuous recording of 27 temperatures within the interior of mature, active hydrothermal chimneys.

During an NSF-funded *Alvin* cruise in May-June 2004, one of the microbial incubators was recovered from the ~200°C structure, Roane, in the Faulty Towers Complex of Mothra (Figures 1 and 2C). The instrument successfully recorded 341 days of data on all 27 probes, which measured discrete temperatures every 20 minutes. In total, more than 600,000 measurements were completed. Well-developed gradients were delineated in each of the three discrete environmental chambers. Numerous perturbations, showing temperature increases up to ~30°C, were recorded simultaneously on all 27 probes (Figure 3B). These data are being examined with co-registered tidal and seismic analyses to determine if changes were induced by storms or seismic activity. The outermost chamber of the instrument was completely filled with sulfate and sulfide minerals; sparse precipitation occurred in the two inner chambers. Microbiological analyses were completed shipboard on numerous samples collected from the insert in Roane (and on additional sulfide samples collected). Ongoing shore-based studies include continued culturing and phylogenetic analyses, and analyses of biofilms on mineral wafers that were placed within the chambers prior to deployment last year. Following recovery of the instrument, a new incubator was redeployed in the same experimental corehole at Roane, showing that the holes can be re-instrumented for time-series studies.

A second data logger was recovered from the 280°C structure, Hot Harold. Data were collected for 189 days on all probes, yielding 367,983 measurements. The temperature history for this high-temperature structure was fundamentally different from Roane, as Hot Harold showed no perturbations even though it is only ~ 25 m away. These results may indicate that porous flow and high-flow-through chimneys are affected very differently by fracturing, tidal, and/or seismic activity. Unfortunately, the barrel assembly could not be recovered from the chimney wall of Hot Harold. Based on these experiments, it was learned that the boreholes seal up after 10 to 20 days and that high temperatures are established within the chambers immediately upon insertion of the instruments. It is also clear that entire instrument assemblies can be easily recovered after 3 months in the higher-temperature chimneys, and that at least some of the chambers will have significant biofilm development.

Three new instruments will be deployed in Mothra in September 2005 using the ROV *Jason 2* and MBARI drill. The new instruments are funded by Ridge 2000 and include four discrete chambers instrumented with temperature probes, an in situ hydrogen sensor, and two osmo-samplers that will allow time-series measurements of hydrothermal fluid from within the incubator. These instruments are scheduled for recovery in 2006.

Macrofaunal Succession on Endeavour; Recruitment Dynamics and Growth Experiments

Through CanRidge funding and in collaboration with the Keck field efforts, data are continuing to be collected that will help describe patterns in larval colonization and aid in understanding the factors affecting subsequent recruitment. In 2004 an attempt was made to recover experimental settlement arrays that had been deployed at different vent sites at Endeavour over the previous 3 years. Each array was made up of 16 plates composed of two different substrates (basalt or scour pads) and, for each plate, two levels of accessibility by grazers (low or high). The arrays were originally deployed in sets in 2001 at two different vents: Smoke and Mirrors (S&M) and Clam Bed. One set was recovered and replaced in 2003, but in 2004, due to inclement weather, the sets of arrays remained in place. Cursory examinations of recruitment panels taken earlier from these sites, combined with digital photographs, indicate extensive recruitment of gastropods and to a lesser degree of polychaetes. Recruitment also appears to be spatially variable, on scales of a few meters (within S&M but not within Clam Bed), as well as 100s of metres (between S&M and Clam Bed). It is hoped that future visits to the two sites will allow for the recovery of the remaining settlement arrays, which will allow continued examination of the temporal patterns in recruitment.

In related work, investigators from Penn State are relating tubeworm morphology at Clam Bed and S&M to biological, chemical, and physical habitat characteristics. Additional ongoing biological work that will complement the study of recruitment processes includes in situ experiments to measure the growth rates of the vent limpet, *Lepetodrilus fucensis.* Limpets were removed from diffuse venting at the Salut vent in MEF and suctioned into four different small boxes, which were placed within a large incubation box, and immersed in a fluorescent dye. Calcein (2,4-bis-[N,N'-di(carbomethyl)-aminomethyl]-fluorescein) binds to calcium, and immersion of *L. fucensis* results in the deposition of a fluorescent mark along the growing edge of the shell; growth (shell length increase) is then measured as the distance between the bright green fluorescent calcein mark and the growing tip of the shell from time of exposure. After 72 hours, the 4 small boxes were removed from the solution and deployed at Salut, 2 in vigorous venting areas, 2 in low venting areas. Upon recovery 13 days later, all animals within 3 of the boxes had died, due to extensive bacteria growth, which clogged the mesh and limited oxygen supply. No visible growth could be determined on the limpets removed from the 4th box, which was collected from one of the low flow areas.

In addition to these studies, the biodiversity and ecological interactions associated with wood in submarine environments was examined. Four long-term experiments were recovered from Endeavour and laboratory analyses are ongoing.

Quantifying Vent-field-scale Heat and Fluid Fluxes: The Sea Breeze Experiment

A sea breeze occurs when the land surface heats more rapidly than the adjacent water, setting up a thermally driven convection current that draws in a cool sea breeze over the land. The central objective of the Sea Breeze program is to examine the hypothesis that, much in the same way, hydrothermal vents within the confines of the axial valley of the central Endeavour Segment entrain ambient waters and this entrainment drives flow of fluid into the valley. Measures of this flow may be an effective proxy for monitoring hydrothermal output.

In the Ridge 2000-NSF-funded Sea Breeze experiment, two sets of complementary observations are being acquired: the vertical fluxes of fluid mass, heat, and salt rising from the Endeavour Segment vent fields, and the lateral transport of fluid mass within the axial valley. The vertical fluxes from the vent fields are measured by establishing appropriate control volumes around them and by box surveys using the autonomous vehicle ABE. These surveys are complemented by precisely navigated CTD (conductivity-temperature-depth) observations and nearby current meter moorings to measure the temperature, salinity, and velocity fields on their boundaries. Summer 2004 was the primary field season for this work to establish the strength of venting at Mothra, Main Endeavour, High Rise, Salty Dawg, and Sasquatch.

In a July-August 2004 cruise on the R/V *Atlantis,* 18 ABE dives (covering 367 km of track) and 42 distinct CTD operations were completed. Over 1000 lowerings of the CTD were completed between 1800 meters and the seafloor. The lateral fluid flux is being measured over the long term with a dense array of five conventional current meter moorings and three up-looking acoustic current profilers. This array was first deployed in July 2003 from CCGS *John P. Tully* to box in the MEF with moorings to the south and north of the field and one mooring on the eastern flank. This array was serviced from the same ship in early August 2004. The southern moorings were moved to the north of High Rise, to allow lateral fluid flux measurements in another field. Processing, analysis, and integration of this substantial data set are in progress. The basic observational array will be recovered summer of 2005 and redeployed for another year.

Toward an Integrated, High-Resolution Map of the Endeavour

Concomitant with flux measurements, the SM2000 sonar mounted on ABE generated high-resolution bathymetric maps of the Mothra, Salty Dawg, and Sasquatch fields. These data are complementary to the *Jason*-mounted SM2000 data collected over three cruises in 2000 that provided continuous coverage from MEF to the northern terminus of High Rise. ABE was also equipped with a magnetometer to continue the "burnhole" studies of Tivey and Johnson (2002) that used magnetic measurements to examine isolated regions of alteration enclosing the fields. These surveys will show how widespread the magnetic burnholes are, and may provide important insight into the nature of upflow zones along the entire Endeavour system.

During the NSF-funded microbial incubator cruise in May-June 2004, the Imagenex sonar on *Alvin* was used to complete an even higher resolution map of Mothra (Figure 4) with survey lines flown at an altitude of 10 m (or more when flying over chimneys). With the exception of the Faulty Towers Complex, the Mothra field had not been well explored or mapped; the other 5 sulfide complexes had only been visited during a single ROPOS and *Alvin* dive. During the May-June program, an area roughly 450 m x 150 m was imaged. Co-registration of these bathymetric maps to lower resolution bathymetry collected on the R/V *Thompson* using the hull-mounted EM300 system is ongoing. In concert, these extremely detailed maps will provide critical baseline data for follow-on geological, chemical, and biological studies within this Canadian Marine Protected Area and Ridge 2000 Integrated Studies Site. The bathymetric maps, coupled with video and still imagery, are providing unparalleled insights into the tectonic controls and geological setting of the hydrothermal vents, and the evolution of the hydrothermal systems.

Significant Gains Toward Understanding the Magmatic Evolution of the Endeavour

A key area of study missing at the Endeavour since its inception as an ISS is a detailed investigation of its magmatic evolution linked to tectonics. Significant progress was made toward this objective during a 5-dive NURP-funded petrology/geology cruise in September 2004 using the ROV *Tiburon.* Two dives were in the axial valley, two on the flanks out to ambient seafloor depths, and the fifth was a complete east-west traverse (Figure 1). All dives were between the latitudes of Salty Dawg and Main fields. Approximately 175 new basalt samples were collected, adding to the ~50 samples previously collected on-axis between Sasquatch and Mothra. All 225 samples are well located on high-resolution bathymetry.

This study followed a dive program to the Cleft segment, and led to a growing realization that Endeavour and Cleft are remarkably similar in some ways. Endeavour is not magmatically dead. Off-axis volcanism is abundant on both the west and east flanks despite there being a modern axial magma chamber beneath only the eastern flank [*Detrick et al.*, 2002]. The two flanks appear to be mirror images geologically, apart from young sheet flows on the ambient seafloor to the east but not west. Mappable units appear coherent for >1 km along strike in the axial valley and on both flanks. Sediment cover is similar in the axial valley and on the flanks out to >2 km off axis. There is an apparent contrast in eruption style between axis (sheets, lobates, and collapse features parallel the valley axis) versus flank (circular diameter pillow tubes orthogonal to the axis). New areas of active diffuse hydrothermal venting were found between High Rise and Main fields, and old vent fields were found on the fault scarps of the axial valley, but no evidence of active venting was found off-axis. Basalts were collected densely enough to combine high-resolution bathymetry and basalt geochemistry to try to map coherent basalt units, to assess whether apparently on-axis lavas differ chemically from apparently off-axis ones, and to determine whether either vary systematically in composition along or across axis.

Building on older efforts, this dive program once again highlighted the fact that volcanism has been “active” both within the axial valley and on the flanks of Endeavour. Although no evidence was found anywhere for “recent” volcanism (within the last few decades), volcanism in the axis appears very young, and volcanism everywhere could be Holocene in age. Axial valley walls up to 1 km off axis appear to be steps of intact, but variably fractured sheet, lobate, and hackly lava flows similar to the youngest lavas seen in collapse features in the axis. The walls are variably covered by pillow lavas, which appear to have been erupted off axis. Coverage by pillow terrane increases with distance off axis and becomes complete after 1 km. The similarity of the east and west flanks suggests that the asymmetric axial magma chamber may be shorter-lived than the off-axis volcanism. Additional sampling in key areas is planned in September 2005 using *Jason 2.*

Modeling Hydrothermal Processes on the Endeavour: Brine Formation and Storage

Since April 2003, the NSF has supported Fabrice Fontaine as a postdoctoral fellow to develop models and study the physical characteristics of the formation and storage of brines within mid-ocean ridge (MOR) hydrothermal systems. This work is done in collaboration with William Wilcock (Univ. Washington) and Michel Rabinowicz (Univ. Toulouse, France) and the Marine Geology and Geophysics group at the University of Washington. In a recent study, the results of which are to be submitted to the *Journal of Geophysical Research,* they question the classical two-layer model for MOR hydrothermal systems in which a single pass seawater cell overlies a dense high-temperature brine cell. According to the results of their models, if brines are stored in a layer at the base of high-temperature hydrothermal systems, they are unlikely to convect because phase separation will lead to a stable stratification. One consequence of this result is that the brine layer beneath low-salinity, black smoker systems must be thin (< 10 m) to match the high-observed heat fluxes. However, estimates of the rate at which brines are accumulating in the crust below the MEF suggest that the brine layer is probably at least 100 m thick. To resolve this apparent paradox, the researchers developed an alternative model in which high-temperature brines with significant salinities (20-25 wt% NaCl) are actually buoyant enough to be collected in upwelling zones. Similar to *Fox* [1990] and *Goldfarb and Delaney* [1988], they argue that interfacial tensions between fluid and solid phases will likely favor the segregation of vapor into the main fractures and brine into the smaller fissures and backwaters. This model allows the vapor to flow efficiently through the system and transport large heat fluxes, while most of the porosity in the lower part of the system fills with brines that rise slowly because of their higher density and viscosity and the low permeability of brine-filled fissures. Finally, their numerical models suggest that the permeability contrast at the interface between the dike and pillow layers acts as a “brine filter” with denser fluids accumulating below the interface and lighter fluids crossing it.

Passive-Acoustic Measurements of Black Smoker Flow

Time-series measurements of many different properties in mid-ocean ridge hydrothermal environments are making rapid progress. However, one important time-series measurement that has been difficult to obtain is flow rate through black smoker chimneys. Flow rate measurements are critical for converting other measurements into heat or chemical fluxes. One possible method for obtaining flow rates involves listening for changes in acoustic intensity or other acoustic signatures near the exits of vigorous black smoker vents. While this method was tried once without success [*Little et al.,* 1990], advances in digital recording technology have warranted a new look into this technique. This past September, University of Washington graduate student Timothy Crone conducted a pilot study to revisit the possibility of using passive acoustic techniques to measure changes in black smoker fluid flow (Figure 2D). He deployed a dual-hydrophone recording system near the 360°C vent called Sully in MEF, and recorded approximately 40 hours of sounds produced by turbulent flow through the structure. This experiment recorded sounds far louder than expected, with significant changes in both the acoustic intensity and in the spectral signature. Crone confirmed that the sounds originated from the vent by measuring the ambient sound field far from the chimney. Most surprising was the observation of coherent tones in the spectral signature that may indicate the presence of acoustic resonators within the chimney. A follow-up field study will be conducted in summer 2005 to confirm these results and further develop the technique for flow monitoring.

Outreach and Education Efforts

Outreach and education efforts included three major programs in 2004: (1) the Dive and Discover program during the May-June microbial incubator cruise with *Alvin,* (2) the REVEL program on the Sea Breeze expedition using ABE, and (3) an undergraduate Research Apprenticeship class taught in the fall of 2004 at the Friday Harbor labs [*McGill et al.,* 2004; *Wilcock et al.,* 2004] that was associated with the Keck seismic program.

The May-June microbial incubator-cruise hosted the Dive and Discover program, which the Woods Hole Oceanographic Institution oversaw. Amy Nevala sailed as a writer and photographer for the website, and produced daily descriptions of cruise operations and science, daily slide shows, and interviews with scientists, students, and crewmembers (http://www.atlantis.whoi.edu/webpages/DiveDiscover). Materials and science information were also provided by the University of Washington. The program was extremely successful, with numerous questions sent to participants at sea by students and the public. Midway through the cruise 13,643 visitors had accessed the website, an average of 1,700 visits per day.

During this same program, Stefan Helmreich, an anthropologist from MIT, joined the cruise to learn more about contemporary vent science. Helmreich is writing a book about the cultural implications of changing scientific knowledge about the sea in an age of deep exploration, DNA sequencing, and digital imaging. As a social scientist, he was interested in seeing how marine scientists study hydrothermal vents and their ecologies, which stretch our conceptions of the very limits of life itself. "Extreme Marine Biology," the tentative title of his book, will draw from his experiences and conversations on the *Atlantis* and *Alvin* to deliver a portrait of how marine scientists are newly imagining the ocean as a network of microbial life hyperlinked to global biogeochemical processes. He is also interested in how hydrothermal sites can be used as analogs to extraterrestrial environments that may support life.

The Sea Breeze program in June-July 2004 hosted the REVEL Project. Seven K- through 12th-grade teachers were selected to participate from across the U.S. (DC, NJ, NY, WA, VW, and WY) and one sea-going mentor who previously sailed in 2000. From June 14 to July 13, the teachers collaborated with scientists aboard the R/V *Thompson* (http://www.ocean.washington.edu/outreach/edu). The teachers not only shared their at-sea experience with a large audience through the web; they also selected a research question, which they investigated, and presented their results to a scientific and maritime audience onboard. After the cruise, these educators distill their experience and research into compelling themes for their classroom teaching, and they share their expertise with their students, school boards, and communities, as well as their peers at regional and national conferences. Since most of the sea-going operations involved remote instrumentation, the REVELers acquired new computational skills while analyzing large data sets. The preliminary results of their cruise research projects were of high quality and resulted in a poster presentation at the American Geophysical Union meeting in San Francisco in December 2004 [*Nassif et al.,* 2004]. Plans are well underway for the summer 2005 REVEL program, and anyone interested can follow along on the website: http://www.ocean.washington.edu/outreach/edu.

The Research Apprenticeship class, which focused on the Keck seismology program, was taught fall 2004 at the UW Friday Harbor labs by William Wilcock, Doug Toomey, Emily Hooft, and Andrew Barclay, and was supported by Keck and the UW. It also involved numerous guest lecturers engaged in the Keck effort. This quarter-long program involved 8 post-undergraduate students from the US and Canada. During this intense study the students learned basic seismology, how to pick and locate proximal and distal events, use triggering algorithms, delineate whale vocalizations in the records, and cross link their data to temperature perturbations detected on other instruments deployed within the Endeavour venting system (Figure 3). The interdisciplinary lectures provided insights into linkages among seismicity, hydrothermal flow and biological activity at the Endeavour Observatory. Each Research Apprentice was responsible for the preliminary analyses of 45 days of data (Figure 3B), and for producing group reports and presentations at the end of the program. In total, they located over 12,000 earthquakes. Their work was presented at the American Geophysical Meeting 2004. This effort was extremely successful and highlights the power that such programs can have in entraining students of diverse backgrounds into RIDGE research.

2005 Field Research Plans

The 2005 field season will involve four programs to maintain and expand the Keck experiment, continue testing the prototype in situ chemical-microbial sensors, and continue the co-registered sampling of fluids, fauna, and chimney material. There will be a multi-investigator (Arizona State, University of Washington, University of Minnesota) NSF-funded *Alvin/Atlantis* cruise, August 13 to September 3, for testing and deploying several new types of in situ sensors. New microbial incubators that measure in situ temperature–H_2, with time-series fluid sampling capabilities will be installed in newly drilled boreholes using *Jason II* on *Thompson* September 1-16. The microbial incubator program will also host the REVEL program. A follow-on 11-day effort funded by the Keck Foundation will maintain the seismic network (pending funding from NSF), recover time-series samplers, and re-deploy several instruments. There will also be a *J.P. Tully* cruise to recover and redeploy the Sea Breeze instruments monitoring currents along the Endeavour Segment. In addition to the three ISS-specific cruises, K. Becker and J. Cowen have *Alvin* dives to conduct borehole experiments associated with IODP drilling of the Juan de Fuca flank east of the Endeavour axis. Details of the Endeavour cruises are provided below.

August 13-September 3, 2005 R/V *Atlantis - Alvin* (Chief Scientist M. D. Lilley)

Smart Sensors for In Situ Monitoring of Hydrothermal Vent Systems (K. Booksh, J. Holloway, Arizona State; M. D. Lilley, University of Washington)

This 10-dive *Alvin* program primarily will test new in situ instruments being developed in a collaborative effort between Arizona State and the University of Washington for use in hydrothermal systems. A new Raman spectrometer is designed to detect major ions as well as organic molecules, and a plasmon resonance spectrometer is designed to measure fluid density. Both instruments are based on fiber-optic technology. In addition, the team will recover instruments that have been measuring fluid resistivity, temperature, and hydrogen concentrations. These instruments will be redeployed on a later cruise. The team will also collect water samples with gas-tight and major samplers for analyses to provide calibration points for the test instruments. The work will focus primarily on the Main and Mothra vent fields, but may include the Sasquatch field to test the instruments in fluids more enriched in chloride.

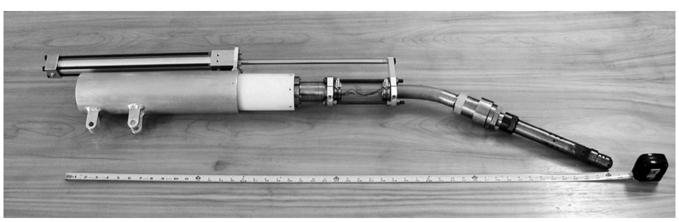
In Situ Sensors for Monitoring the Chemistry of Hydrothermal Fluids: Experimental Calibration and Field Applications (W. Seyfried and K. Ding, University of Minnesota)

This 4-dive program on Endeavour will continue research on time-series and in situ chemical measurements of high-temperature and diffuse-flow venting. The electrochemical array of each of the chemical sensor packages developed at the University of Minnesota permits determination of pH, dissolved H_2 and dissolved H_2S, as well as temperature. In addition to direct measurements in vent fluids using a sensor probe mounted on the *Alvin's* starboard manipulator (Figure 5, top), which displays and records data in real-time to a laptop in the sphere, self-contained chemical data-logging instruments will also be deployed (Figure 5, right). These units were first used at EPR 9°50'N (February 2004) and provided simultaneous chemical (pH, redox) and temperature records for biologically active vent systems for up to 13 days. Three electrochemical units have been built and all will be deployed during the JDF field study. Although specific deployment plans are not yet final, it is likely that the efforts will focus on high- and low-temperature systems at or near the Main Endeavour Field, with deployment times exceeding previous efforts.

The *Alvin* expedition will also sample fluids from the instrumented vents using both major bottles and gas-tight samplers. The gas-tight samplers developed by Jeff Seewald at WHOI offer many advantages over the titanium syringe major samplers in that they provide accurate temperature and fill control during sampling and allow dissolved gases to be determined using a gas chromatograph immediately after each dive. Shipboard knowledge of gas chemistry of vent fluid samples has a tangible effect on in situ sensor deployment strategy. Another objective will involve sampling chimney material at the same vent sites at which in situ sensors are deployed. Chimney mineralogy provides indirect, yet potentially useful information as a means of constraining redox and pH of coexisting vent fluids, especially involving phases (sulfides, oxides) that line the inner chimney wall and are more closely linked in time and space to the actively venting fluids.

COMRA: China Ocean Mining Research Association

In addition to these programs there are also 4 *Alvin* dives funded by the Chinese organization COMRA to gain submersible experience and examine the vents at the Endeavour.



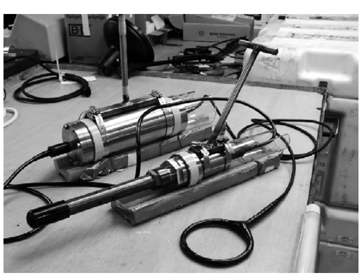


Fig. 5. (top) Chemical probe showing hydraulic mount that fits on *Alvin's* starboard manipulator. (right) One of the self-recording temperature sensors developed by the Univ. Minnesota group and deployed during this leg.

September 1 - September 16, 2005 R/V *Thomas G. Thompson – Jason 2* (Chief Scientist D. S. Kelley)

Determining the Limits to Life in Submarine Hydrothermal Systems: Active Sulfide Deposits as Natural Laboratories (D.S. Kelley, M.D. Lilley, J.R. Delaney, J. Baross, University of Washington; C.G. Wheat, MBARI; and P. Girguis, MBARI/Harvard)

During the first day of this expedition there will be a one-day engineering dive for *Jason 2*. This main thrust of this field program is focused on deploying and testing three new, instrumented in situ microbial incubators within the Mothra and Main Endeavour Hydrothermal Fields using *Jason 2*. These instruments are designed to explore the boundary conditions that limit the growth and survival of microbiological communities within the walls of diffusely venting sulfide chimneys. Each incubator contains arrays of 27 temperature probes, an osmotic sampler, H_2 sensor, and culturing substrates. Spatially coregistered environmental and microbiological information will be used to begin quantifying the physiological diversity of microorganisms within different thermal-chemical environments. During this program the MBARI drill mounted on *Jason 2* will be used to drill new core holes within the chimneys for deployment of the incubator observatories. One of the incubators will be recovered on the follow-on Keck cruise, processed, and redeployed. Co-registered discrete major and gas-tight fluid samples will be taken at these sites. All three instruments will be recovered in 2006. Co-registered temperature, H_2, and time-series fluid measurements will be correlated to temperature-resistivity-H_2 measurements in nearby, vigorously venting black smoker chimneys, and with year-ong, continuous seismic measurements. Time allowing, additional holes will be drilled in (1) basaltic substrates for future deployments of short-period seismometers and (2) areas of diffuse flow in basalts from deployment of additional incubators. Time allowing, additional water, macrofauna, and microbiological sampling will be completed. This expedition will also host the REVEL program (http://www.ocean.washington.edu/outreach/edu) and maintain an active web site through the new satellite system on the R/V *Thompson* that continuous access to the web in real-time.

September 19-September 30, 2005 R/V *Thomas G. Thompson – Jason 2* (Chief Scientist J. R. Delaney)

This intense 11-day field program is presently focused on recycling all of the Keck hydrothermal instruments and recovering some of the seafloor seismometers. If a pending NSF proposal is successful, then the Keck seismic instruments on the Endeavour will be redeployed for 3 more years with the addition of a second broadband in 2006. If the seismic proposal is successful, the following instruments on the Endeavour will be recovered, processed and redeployed: data loggers and battery packs for 7 short-period and 1 broadband seismometers, two remote access samplers and one particulate DNA sampler, four temperature-resistivity-H_2 probes, a current meter, and pressure sensor. An experimental hydrothermal package deployed in a seep at Nootka will also be recovered. This instrument array (flow meter, temperature-hydrogen-resistivity probe, and heat flow probe) has been providing real-time data to shore via the WHOI-buoy for several months (http://nootka.ocean.washington.edu/). In addition to the instrument program, SM2000 mapping will be undertaken during periods of opportunity to continue the high-resolution mapping effort at this IS site as will clean up of the fields. This expedition will also host the REVEL program.

CCGS *John P. Tully* Sea Breeze (Chief Scientist R. Thomson)

As currently planned, the *J.P. Tully* will recover and redeploy the moorings that now bound the High Rise Field. Additional funding is being sought to keep this array in place, with augmentation through NEPTUNE Canada.

Funded and Pending Programs

To address a missing key component in Endeavour ISS studies, a proposal has been funded to investigate the 3-D structure of the crust and upper mantle beneath this intermediate-spreading system. In the next few years, D. R. Toomey, E. Hooft Toomey, W. S. Wilcock, and A. H. Barclay will carry out their proposal, "Testing Models of Magmatic and Hydrothermal Segmentation: A 3-D Seismic Tomography Experiment at the Endeavour Ridge." This experiment will consist of 64 three-component ocean-bottom seismometers covering an 80 km section of the Endeavour Ridge.

In addition to the Toomey et al. program, there are pending proposals submitted to NEPTUNE Canada to transition the seismic array onto the cabled seafloor observatory, as well as to build and deploy an extensive suite of in situ chemical, biological, and hydrothermal sensors. The NEPTUNE Canada program is evaluating proposals for the backbone and node infrastructure, with the goal of having a contract finalized in summer 2005. NEPTUNE Canada has $13M CAD funding earmarked for building community experiments. Proposals for a community hydrothermal experiment at the Endeavour and for a NEPTUNE Canada seismic network that will include a local array at the Endeavour are now pending, with notification anticipated for spring 2005. To address questions about the magmatic evolution of this site, another proposal is pending for detailed geochemical, volatile, and chronological analyses of the extensive suite of basalt samples collected at the Endeavour in 2004.

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- The Earth Institute, Lamont-Doherty Earth Observatory, Columbia University
- School of Earth and Atmospheric Sciences, Georgia Institute of Technology
- Department of Earth and Planetary Sciences, Harvard University
- Eberly College of Science, The Pennsylvania State University
- Department of Biology, The Pennsylvania State University
- Vent Biology Group, The Pennsylvania State University
- Scripps Institution of Oceanography
- Department of Geological Sciences, University of Florida
- School of Oceanography, University of Washington
- Department of Earth and Planetary Sciences, Washington University in St. Louis
- Woods Hole Oceanographic Institution

Ridge 2000 Steering Committee

Ridge 2000 Executive Committee

For mailing addresses, e-mails, and phone numbers, please check the Web site: www.Ridge2000.org > About Ridge 2000 > Steering Committee.

Update from InterRidge

InterRidge (IR) has settled in well at its new home base in Kiel, Germany. In addition to maintaining its coordination duties, ranking at the top of the IR team agenda this year are two primary initiatives: designing new ways of engaging the scientific community in international ridge collaboration and spearheading new initiatives to deliver ridge science to public audiences.

IR is currently supported by 2700 individuals from 5 full-member nations (France, Germany, Japan, UK, USA) and 6 associate member nations (Canada, China, India, Korea, Norway, Portugal). Seventeen other nations have corresponding nation status. In May 2004, the IR office moved to the Leibniz Institute of Marine Sciences in Kiel, Germany, when the IR chair, Colin Devey, became head of the "Dynamics of the Ocean Floor" research group. IR will be hosted by the Institute through the end of 2006.

The move to Germany coincided with the kickoff of the next decade plan for IR, which you can find in full on IR's website: http://interridge.org. In short, IR aims to fulfill four basic functions: (a) build and maintain an international ridge-research community; (b) identify through its working groups (Table 1), and the workshops and meetings they organize, the important problems in ridge research and develop program plans for their solution; (c) act as a representative body for ridge scientists in policy discussions; (d) communicate the importance of ridge research to the general public and decision makers worldwide through education and outreach programs.

The IR office team includes Katja Freitag and Kristen Kusek. Katja, the office coordinator, is based in Kiel, Germany, and Kristen, E&O coordinator, is in St. Petersburg, Florida, USA. Office projects have included restructuring the IR website, which was launched in February 2005; introducing a new IR logo in September 2004; and designing and printing an IR flier. Other tasks have included working with Ridge 2000 to organize the Back-arc Basin Theoretical Institute in Korea and the Cyprus field school and field trip, and coordinating the Indian Ridge workshop in Goa.

IR-hosted Events

Indian Ridge Workshop. From 19–21 January 2005, the National Institute of Oceanography hosted a successful workshop on Indian Ridge Systems. More than 80 participants attended, a third of whom came from outside of India. It is evident that India has established itself as a ridge-researching nation; however, India welcomes more collaborative work with other nations, especially for training young scientists in the newest research technologies. The need to study the little-known biology of the Indian ridges was also named as a research priority.

Field School and Field Trip (organized together with the US Ridge 2000 office). A field school, with 38 participants, and field trip, with 21 participants, were both led by Professor Joe Cann (UK) to study the Troodos ophiolite in Cyprus (May 2005).

Table 1. InterRidge Working Groups

Theme	Objective	Start	WG-Chair
Ultraslow-spreading ridges	To concentrate on the particular scientific and coordination problems posed by ultraslow ridges	2004	Jon Snow, Mainz, Germany
Ridge-hotspot interaction	To better understand the physical and chemical interactions between mantle plumes and mid-ocean ridges and their effects on seafloor geological, hydrothermal, and biological processes	2000	Jian Lin, WHOI, USA Jérôme Dyment, CNRS, France
Back-arc spreading systems	To summarize past work on back-arc basins (BAB) and coordinate future studies	1995	Sang-Mook Lee, SNU, Korea
Mid-ocean ridge ecosystems	To increase international collaboration in hydrothermal biological studies and work on integrating ridge-crest biological and geological research	1994	Françoise Gaill, CNRS, France Nicole Dublier, Bremen, Germany
Monitoring and observatories	To promote long-term ocean bottom observatories To establish a long-term observatory in the Atlantic	2002	Javier Escartin, IPG Paris, France Ricardo Santos, Azores, Portugal
Deep earth sampling	To strengthen the ties to, and use of, global deep earth sampling facilities such as IODP, ICDP, etc.	2004	Benoit Ilsedefonse, Montpellier, France
Global exploration	To address the need for more basic data about many of the world's spreading axes		*To be announced*
Biogeochemical interactions at deep-sea vents	To address questions of biogeochemical interactions in different MOR and BAB environments and link scientists and their needs for technologies and sampling time	2004	Nadine le Bris, IFREMER, France

3rd International Symposium on Hydrothermal Vent and Seep Biology. Horst Felbeck is organizing the symposium be held at the Scripps Institution of Oceanography, La Jolla, California, USA (September 2005). Register on the Ridge 2000 website: www.Ridge2000.org

InterRidge Working Groups

The Mid-ocean ridge ecosystem working group, together with the IR Steering Committee, is formulating a voluntary code of conduct for scientific work at hydrothermal vents to establish the position of scientists as stakeholders with expert knowledge. The IR chair was invited to talk at an International Seabed Authority workshop in Jamaica (September 2004) to discuss InterRidge and its potential relevance to establishing environmental baselines, as well as potential collaborations with the Authority. IR is finding international recognition as a representative body for ridge scientists in policy decisions.

The first Biogeochemical interactions at deep-sea vents working group meeting was held in San Francisco at the AGU meeting (December 2004). This was a successful starting point for the working group, and a report is available on the outcome on the IR website.

Working group meetings:

Monitoring and observatories working group: an International MOMAR implementation meeting held in Portugal (April 2005)

Ultraslow-spreading ridges working group: planning a meeting in Italy (February or March 2006)

Deep earth sampling working group: planning a meeting with IODP (first half of 2006)

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Ridge 2000 Education and Outreach

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way of reaching subsets of the public—in some instances, more effective than online publicity. Our priority audiences are those who are likely to be most receptive to our key messages, such as people who have a preexisting interest in science, technology, natural history, or the environment. These people are more likely to read certain publications, receive particular broadcast media, and visit specific locations (such as aquaria or museums) for recreational purposes. Therefore, as well as maintaining www.venturedeepocean.org, we aim to increase publicity via these other channels—highlighting the website as a source of further information where appropriate. For example, we have invited journalists to accompany the Lau cruises: to date Kristen Kusek has sailed with cruise 2, and Bryan Nichols with cruise 3. These professionals are not only providing key material for the website, they are writing articles for magazines and other media.

As ever, there is not enough space to cover all we would like to tell you about this initiative. Please don't hesitate to get in touch if you want to know more, if you have comments or suggestions, or if you would like www.venturedeepocean.org to feature your research. For information, contact Liz Goehring, exg15@psu.edu, or Catherine Williams, csw14@psu.edu.

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RODES

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Although the data system is in its early stages of development and many data types are not yet available, we have chosen to provide access to the data holdings as they grow, with the anticipation that community use will help guide the ongoing development of the system. To design the system to best serve the broad community needs, community feedback is essential. We encourage everyone to try out the system and send us comments on any aspects, especially usability and content.

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If you would like to know more about the outcomes of working group meetings and find information on IR activities, please check the website (www.interridge.org) or contact Katja Freitag (coordinator@interridge.org) directly.

InterRidge Education Outreach

Last year, IR teamed up with a long-time producer of marine science educational television programs (Future Vision: Educational Media Group) and other science organizations in a cost-effective plan to develop innovative print and video media products for formal and informal audiences. Funding is pending. The plan is to join groups that traditionally do not work together—scientists, writers, educators, video producers, graduate students—in a common mission: to develop an educational video package including six half-hour programs that tell the compelling stories of ridge science in an effective, accurate way. Also under development is a Science Writer At Sea initiative, where journalism graduate students will be offered the opportunity to participate in research expeditions. The program aims to: communicate the compelling stories of life and research at sea to nonscientific and scientific audiences; bridge the gap that often exists between scientists and journalists through a 'real time' experience; and generally encourage interest in the mysteries of the deep in diverse audiences worldwide. Please contact Kristen Kusek for more information (kristenkusek@aol.com).

Troodos Ophiolite Field Programs Yield Lessons about Oceanic Ridge Processes

Sharon Givens *(Ridge 2000 Program Office),* Kristin Ludwig *(U of Washington),* Nicholas Hayman *(Duke U),*
and the Ridge 2000–InterRidge Field Program Participants

Famous for its role in the plate tectonic revolution, the Troodos Massif in Cyprus still baffles researchers, but the ophiolite's importance lies in the insights it gives those who study modern oceanic ridge processes.

The ophiolite shared its assets recently with graduate students, postdoctoral fellows, and senior scientists attending the Ridge 2000–InterRidge field school (3-11 May) and field trip (12-19 May). The 38 field school participants and 19 trip participants viewed classic outcrop evidence for the ophiolite's renown, and heard arguments supporting and refuting various aspects of its formation, tectonic setting, hydrothermal processes, and faulting. Some controversies regarding the Troodos may never be settled, according to trip leader J. R. "Joe" Cann (University of Leeds).

Despite its puzzles, the Troodos ophiolite easily complements the study of modern oceanic ridge processes. A superb type location for ophiolites, Troodos gave Ridge 2000 junior and senior scientists an exceptional three-dimensional view of relatively unaltered, ~90 ma ocean crust. During their days in the field, participants explored a wide array of field relationships of marine geologic sequences that will help them better understand the rock types associated with modern ridge systems.

With the help of an extraordinarily skilled bus driver navigating the twists and turns of narrow Cypriot roads, both groups visited as many as six outcrops on the ophiolite each day. They saw up close the evidence that made Troodos famous: serpentinized mantle periodotites, gabbros and sheeted dyke complexes, basalt pillows, hydrothermal vent stockwork, ochre and umber deposits, the remains of chromite, asbestos, and copper mining, and the telltale signs of detachment faulting. Field excursions were arranged by theme, detailed in Cann's useful field handbook. The outcrops provided the context for lively discussions about ridge processes and debate about the ophiolite's history.

Joining Cann as field school lecturers were Troodos experts John Malpas (University of Hong Kong), Julian Pearce (University of Cardiff), and Costas Xenophontos (Cyprus Geological Survey). Three other ridge scientists rounded out the lecture team: Juan Pablo Canales (Woods Hole Oceanographic Institution), Peter Michael (University of Tulsa), and Debra Stakes (Monterey Bay Aquarium Research Institute and University of California, Santa Cruz). Malpas and Xenophontos continued with Cann to lead the field trip.

Participants included numerical modelers, geochemists, geophysicists, geologists, biologists, engineers, and microbiologists, some of whom had no experience on a rock outcrop. By the end, though, even the less experienced could identify geologic features such as, for example, the chilled margins within a dyke swarm. The participants hailed from large U.S. oceanographic research institutions to smaller state universities in the U.S., as well as from universities in Britain, China, Germany, Israel, Italy, Japan, and Switzerland.

Field school day 1, stop 2: Groups led by Julian Pearce (left) and John Malpas (right) observe cross-cutting extrusive sheet flows of lava with characteristic columnar jointing in an upper-crust exposure at Kamara Potamos on the Troodos Massif in Cyprus. (Photo by S. Givens, Ridge 2000 Program Office)

While the field trip was devoted to outcrop excursions, the field school included lectures and poster sessions, the latter where students informally presented their current research about ridge processes. Poster topics included the dynamics of ridge jumps and ridge-transform intersections, the evolution of vent fluids from serpentine-hosted hydrothermal systems, deformation mechanisms in the crust and mantle, and microbial ecology associated with hydrothermal venting in the crust.

Seminar topics reflected the expertise of the lecturers. Xenophontos kicked off the seminars with a 50-year history of geological survey work on the Troodos Massif. Pearce, Malpas, and Cann followed with geochemical evidence for a supra-subduction zone setting of the ophiolite, a history of the plutonics found near Mt. Olympus, and evidence for seafloor hydrothermal systems. Canales, Stakes, and Michael presented current thinking about seismic imaging of oceanic ridge systems and linkages between geochemical, hydrothermal, and biological processes. The lectures were useful for understanding the outcrops and applying the lessons of Troodos to modern seafloor processes.

As repeatedly pointed out by Cann, Malpas, and Xenophontos, the Troodos ophiolite suffers from several decades of controversy revolving around the arc signature of the volcanics; the nature of the spreading center and its tectonic setting; the timing, location, and nature of hydrothermal processes; and the role of faulting with respect to the Solea Graben. Further, the details of faulting, magmatic deformation, and multiple mantle-derived melts elude straightforward explanations. Despite the unresolved problems, the >100 km extent of sheeted dikes and the upper contact with extrusives provide ample evidence of seafloor spreading.

Obtaining High-Resolution Chronologies of Submarine Lava Eruptions: Better Dating Through Radiochemistry

Ken Rubin and Iris van der Zander, *Univ. of Hawai'i*

Seafloor volcanic eruptions can be wonderfully useful events, providing windows to study magmatic, hydrothermal, and biological processes in the crust and opportunities to observe punctuated changes in deep-sea environments and ecosystems, which is one basis for Ridge 2000 Time Critical Studies. Because eruption-related phenomena tend to be highly transient, with most signals decaying over days to months, we will describe here how the community can best take advantage of radiometric techniques to date eruptions.

Two issues plague the time-critical studies of submarine eruptions: (1) detecting events and (2) establishing chronologies for detected or suspected events. At the University of Hawai'i, we have successfully used radiometric methods for dating lavas as one means to establish eruption chronologies, including a recent eruption in 2003 at 10°44'N on the EPR [*Voight et al.,* 2004]. We discuss our experience to illustrate the limitations and logistical constraints on the application of radiochemistry to this problem. Our goal in this article is to alert the community that the capability exists, and to pass along information that will maximize the quality of results when the next opportunity arises.

Submarine Eruptions—When did they occur?

It is difficult to detect volcanic eruptions on the global submarine ridge system, and trickier still to obtain observations immediately following one [e.g., see review in *Perfit and Chadwick,* 1998]. Historically, such eruptions have either been detected acoustically [e.g., *Fox et al.,* 1995] or by fortuitous arrival of research teams at a recent eruption site [e.g., *Haymon et al.,* 1993]. In either case, rock radiometric dating can establish high-resolution eruption chronologies, which are particularly useful for interpreting subsequent evolution of the volcanic system and related environmental changes. In addition, for eruptions not detected acoustically, radiometric dating provides an unambiguous means to confirm if and when a suspected eruption occurred.

During a November 2003 biological sampling visit to the EPR at 10°44'N [*the FIELD cruise, J. Voight, PI*], *Alvin* divers expected to be revisiting an established hydrothermal vent field. Instead, they found fresh rock, bacterial mats, and diffuse snow blower vents issuing from lava collapses, and they suspected a recent eruption [*Voight et al.,* 2004]. Not sure of how "old" the event was, the science team acted quickly after the cruise to send our Hawai'i group lava samples for dating. We determined that an eruption had occurred within 1 to 2 months prior to their visit to the site, which is in the midst of the 8-11°N ISS [*van der Zander et al.,* 2004]. This area has been covered by the N-EPR hydrophone array since 1996, which is not monitored in real time, and unfortunately, no data was recorded during the 2002-2004 deployment due to a hardware glitch (Bob Dziak, pers. comm., 2004). Although we have missed an opportunity to compare the two records, the serendipitous eruption discovery and radiometric dating provided the first opportunity to study such an event at a magmatically starved fast-spreading ridge crest.

Radiometric Lava Dating Methods, Timescales, and Resolution

Ages for lavas erupted within the past 1.5 to 2 yrs can be determined with the ^{210}Po-^{210}Pb dating method [*Rubin et al.,* 1994]. To use this method, analyses should begin as soon as logistically possible after samples are collected from suspected eruption locales. Radioactive disequilibrium is largest and temporal resolution of the method is highest immediately following eruption.

Here is how the dating system works: Polonium is volatile at magmatic temperatures and degasses from magmas when they erupt. This creates an initial ^{210}Po (half life=138.4 day) deficit relative to grand parental ^{210}Pb in freshly erupted magmas (Figure 1). This deficit is subsequently erased with time via radioactive ingrowth toward secular equilibrium. Repeated analyses of ^{210}Po are conducted by alpha-spectrometry of a dissolved sample solution over 1 to 1.5 yrs, and the eruption age is determined by best-fit regression to a radioactive ingrowth curve. Dating resolution depends on a clock that starts with eruption and winds down in just a couple of years. Errors from extent of initial Po degassing and how well spaced analyses are on the ingrowth curve are explained in the Figure 1 caption. In essence, the sooner after eruption analysis begins (a function of sampling infrastructure availability, sample processing speed, and luck), the better the ingrowth regression is. Sample requirements are described below.

The ^{210}Po-^{210}Pb dating method was originally developed in response to unprecedented biological and volcanological observations by submersible divers at 9°50'N on the EPR in 1991 [*Haymon et al.,* 1993]. Since then, it has been applied successfully to eruptions on the EPR, Gorda Ridge, Loihi Seamount, Boomerang Seamount (SE Indian Ridge), and Rota seamount in the Marianas [*Rubin et al.,* 1998; *Garcia et al.,* 1998; *Johnson, et al.,* 2000; *van der Zander et al.,* 2004]. Temporal resolutions of these results have been variable (<2 to 3 months), largely related to when analyses were begun relative to the eruption date.

The Gorda and Loihi studies were responses to seismically detected eruptions (Gorda by SOSUS and Loihi by the USGS seismic net on land at nearby Kilauea volcano). Thanks to NSF support provided with

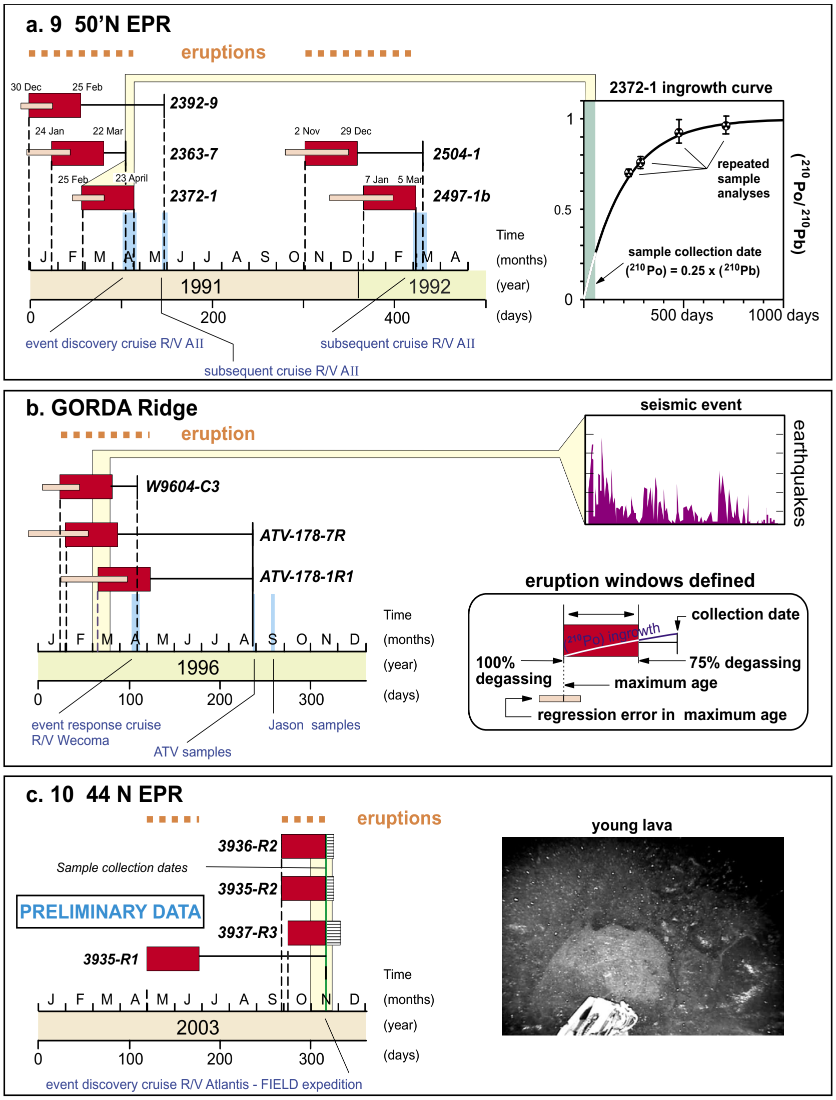

Fig. 1. ^{210}Po-^{210}Pb dating results from 3 eruptions on the EPR and Gorda Ridges. Ages are given as eruption windows (black bars), which represent unavoidable uncertainty in the extent of initial Po degassing. Heavy dashed lines show likely eruption intervals. Po is completely degassed upon eruption at subaerial and shallow submarine volcanoes [see review by *Rubin,* 1997]. We are not certain this occurs at oceanic depths of 2-3 km, so we report an "eruption window" based on a conservative minimum degassing estimate and 100% degassing. The 2-month window we currently report is based on observations at 9°50'N EPR (panel a), although the still preliminary data from 10°44'N EPR (panel c) may allow us to narrow eruption window widths because 3 of 4 samples were >75% degassed of Po upon sample collection. Errors in maximum age (gray horizontal bars) reflect data regression and analytical errors (see the eruption window inset). Sample collection dates are depicted by a --I, coinciding with cruises to those areas (vertical gray bars). Absolute and relative times are given at the base of the plot. Note the difference in error on maximum ages for Gorda samples taken in April and August 1996 (ages overlap for all samples in panel B but early sampling led to much higher resolution ages). The young lava flow image is a video frame grab from *Alvin* dive 3935 of the FIELD expedition [*provided by Robert Zierenberg*]. An example ingrowth curve and the seismic record that led to the Gorda event response are also shown, tied to calendar time and sample ages.

record-breaking speed, response cruises to these events were mounted within weeks, and fresh lava samples were recovered for ^{210}Po-^{210}Pb dating. The Gorda radiometric dates fell within the detected dates of the seismic swarm, but at Loihi seamount (Hawaii), dating showed that lavas were erupted several months before the seismically detected event, which formed a new pit crater on the summit and brecciated the young lava flow.

The other studies came about from fortuitous arrival of research teams at recent eruption sites. In each case, shipboard scientists insightfully interpreted seafloor or near bottom observations as probable indicators of a submarine eruption. Since none of these events were detected remotely, the subsequent radiometric age dates provided the only quantitative eruption timing data.

Collectively, these studies indicate that ^{210}Po-^{210}Pb dating can do more than confirm visually based indications of suspected eruptions. At 9°50'N EPR, for example, we also documented in the same area two discrete eruptive events separated by about 6 to 12 months [*Rubin et al.,* 1994; see Figure 1]. The radiometric eruption dates are consistent with rapid changes in vent water chemistry seen in time-series analyses, including a reset of the system in early 1992 [*Von Damm et al.,* 1995].

A similar story of prolonged eruption is emerging from work still in progress on the 2003 eruption at 10°44'N EPR, where the time between eruption and first sample analysis is so short that we may get the highest resolution dates yet [*van der Zander et al.,* 2004].

We also employ a second, lower-resolution dating approach, which does not require rapid-response sampling. It uses ^{210}Pb-^{226}Ra radioactive disequilibria (half life = 22 yrs) to date eruptive events over the past century at decadal to semi-decadal resolution [*Rubin et al.,* 2001; *Bergmanis,* 2003; *van der Zander et al.,* 2003]. This method is useful for determining eruption recurrence intervals (e.g., at recent eruption sites by comparing the youngest lava and samples of antecedent lava flows). Unlike ^{210}Po-^{210}Pb where the clock is set by eruption, ^{210}Pb-^{226}Ra radioactive disequilibria are petrogenetic. This and the generally small radioactive disequilibria in MORB (<15%) add to the uncertainty.

How To Obtain Dates, and Associated Costs

Because of the short half-life, ^{210}Po-^{210}Pb dating should be considered for at least 1-3 samples as soon as suspected lava flows are sampled. ^{210}Po dating is a race against the clock and each delay (avoidable or not) takes resolution away from resulting dates. Any radiometric counting facility should be able to conduct the analyses for ^{210}Po-^{210}Pb dating. Each eruption is different (timing, sampling, sample composition), but it is generally best for investigators who are thinking of having some dating work done to contact their laboratory of choice as soon as possible to plan for the work, so that sample condition, quantity, and transportation logistics can be discussed. At present, the SOEST Isotope Laboratory at the University of Hawai'i, with funding from NSF-MGG, can provide the radiometric dating to PIs at no charge. For almost 8 years, NSF-MGG has funded radiometric dating analyses via the RREADI (Recent Ridge Eruptions And Dating Investigations) and RREADI-2 projects. As a result, the SOEST Isotope lab has in place the infrastructure and prior experience needed to achieve a quality date in short turnaround. NSF-MGG has indicated a preference to fund analyses on a case-by-case basis via supplements to existing projects, a method we have recently used to date 4 lavas from the 10°44'N EPR event.

Analytical Details for Radiological Assays and Sample Requirements

Glass samples to be dated can be chipped from rock fragments or sent to the lab still attached to the rocks. In the SOEST lab, we dissolve 2-5 grams of microscopically inspected clean (unaltered-phenocryst free) normal MORB glass for a complete high-resolution assay. It is easiest and fastest to pick glass from a large sample pool (~25 grams). Our experience is that adequate material can be picked from a very fresh MORB sample in ~2-3 weeks. Sample prep and analyses are conducted in our clean laboratory. Minimal sample cleaning and handling outside of such a lab is preferable. Material for analysis can be rinsed in de-ionized or millipore water and dried at <75°C, but other common shipboard and/or lab-based sample "cleaning" methods for petrologic analysis (water or acid washing in sonic baths) should be avoided. If enough sample is available, it is useful to make additional U-series analyses (^{238}U-^{230}Th-^{226}Ra-^{210}Pb-^{232}Th) by thermal ionization mass spectrometry, and to apply the ^{210}Pb-^{226}Ra chronometer, which uses the longer-lived isotopes to measure petrogenetic timescale variations and seawater alteration signatures. At SOEST, these analyses are conducted on the same glass dissolutions as the ^{210}Po analyses and use about 25% of the total material.

Acknowledgments

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First In Situ Raman Spectroscopic Measurements at Hydrothermal Vents—Sea Cliff Hydrothermal Field, Gorda Ridge

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J. J. Freeman *(Washington University, St. Louis)*

A team of scientists and engineers at MBARI have developed a sea-going laser Raman spectrometer, DORISS (Deep Ocean Raman In Situ Spectrometer), by modifying a laboratory model laser Raman spectrometer for in situ operations in the deep ocean up to 4000 m depth (Figure 1A) [*Brewer et al.,* 2004; *Pasteris et al.,* 2004]. Our group has deployed the DORISS system a number of times in Monterey Bay and in the Gulf of California for testing, to conduct experiments in gas dissolution [*White et al.,* 2004], and to analyze natural gas venting from the seafloor [*White et al.,* 2003]. In July 2004 using the ROV *Tiburon,* we deployed DORISS at hydrothermal vents in the Sea Cliff Hydrothermal Field on Gorda Ridge. This was the first time in situ Raman measurements have been attempted at hydrothermal vents. Raman spectra were obtained from high-temperature hydrothermal fluids, minerals such as anhydrite and barite, and bacterial mats.

Raman spectroscopy is a type of vibrational spectroscopy in which a target is excited by monochromatic laser light and the inelastically scattered light provides information about the composition and structure of the target. Because Raman spectroscopy requires little to no sample preparation, and can be used to analyze solids, liquids, and gases, it has the potential to be a powerful technique for in situ geochemical measurements in the deep ocean. A number of targets in hydrothermal vent environments are Raman active. These include gases dissolved in hydrothermal fluids, such as CO_2, CH_4, and H_2S. Hydrothermal minerals such as anhydrite, barite, sphalerite, chalcopyrite, and others are Raman active [*Pasteris,* 1998; *Wang et al.,* 2003]. Raman spectroscopy has also been used in the laboratory to analyze elemental sulfur produced by deep-sea bacteria such as *Thioploca* and *Beggiatoa* [*Pasteris et al.,* 2001].

Analyzing opaque targets such as rocks poses more of a challenge than transparent targets because of the stringent positioning requirements of the DORISS probe head. The focal depth of the probe head is on the order of 0.1 to 3 mm depending on the sampling optics. Thus, the probe head must be positioned with a precision of approximately 0.1 mm to be able to obtain Raman spectra from opaque targets. For this reason, we developed and built the Precision Underwater Positioner (PUP) [*Kirkwood et al.,* 2003]. PUP (Figure 1B) consists of a tripod frame and three actuators providing 3 degrees of movement—Z axis (15 cm up-and-down), R-axis (15 cm in-and-out), and theta axis (58° rotation about the Z axis). A camera, light, and red lasers that cross at the DORISS focal point assist the shipboard scientist in positioning the probe head.

Sea Cliff Hydrothermal Site

The Sea Cliff Hydrothermal Field is located on the northern end of Gorda Ridge, an intermediate rate (~55 mm/yr) spreading segment in the northeastern Pacific Ocean. Hydrothermal activity is located approximately 2.6 km east of the spreading axis at a depth of 2675

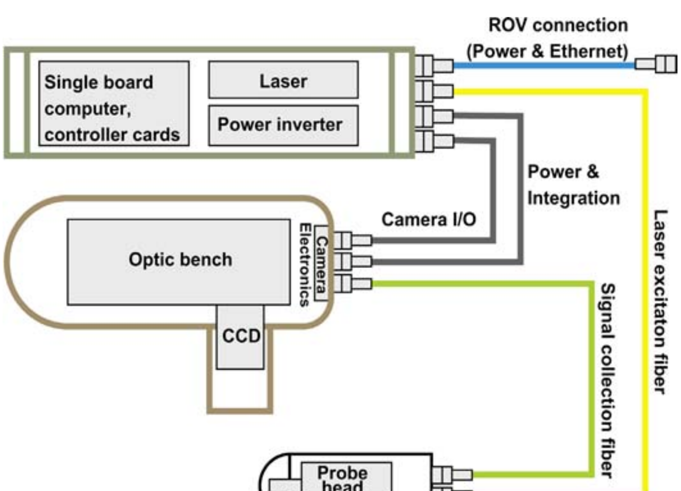

Fig. 1. *(left)* The DORISS instrument is a Kaiser Optical Systems laser Raman spectrometer modified for deep-ocean use and divided into three 4000 m-rated pressure housings (modified from Brewer et al., 2004). *(right)* The Precision Underwater Positioner (PUP) is used to position the DORISS probe head (mounted at left) with a precision of ~0.1 mm.

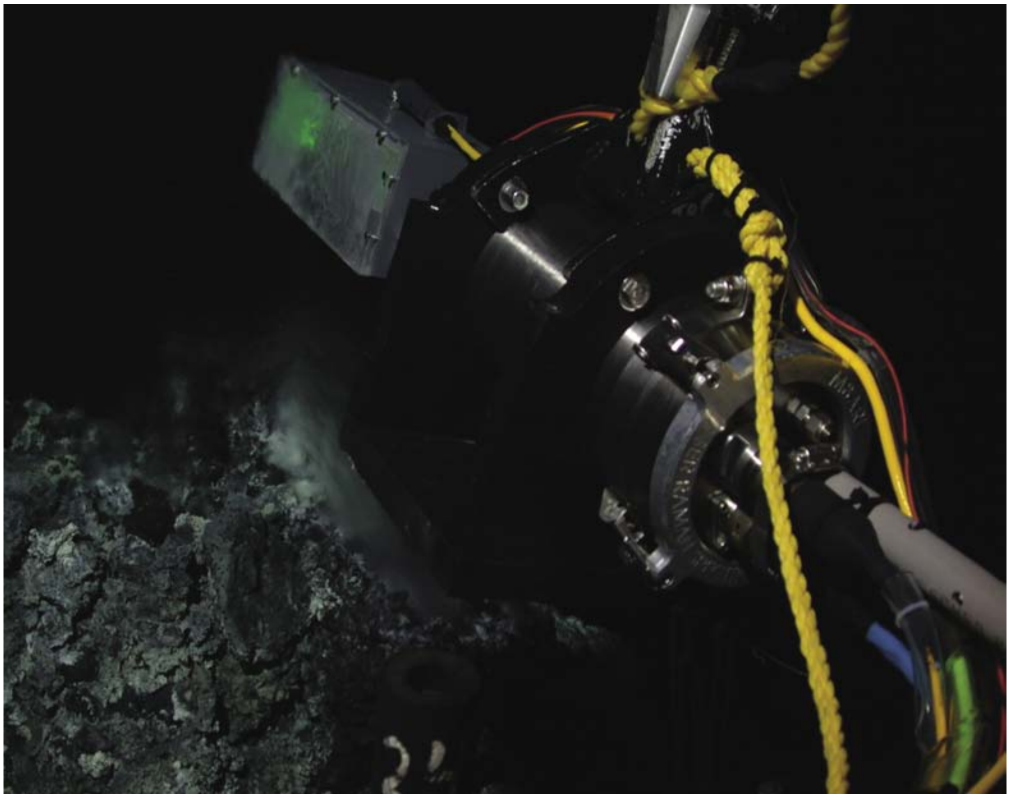

Fig. 2. The probe head is used with an immersion sampling optic in an open-bottomed box to collect buoyant vent fluid for analysis

to 2800 m (~300 m above the axial valley floor). The site was first identified by water column anomalies in 1986 [*Baker et al.,* 1987], and first visited by the U.S. Navy submersible DSV *Sea Cliff* in 1988 [*Rona et al.,* 1990]. Active venting is concentrated along ridges that trend perpendicular to the slope of the eastern axial valley wall (022°). The chimneys formed along these ridges are primarily composed of anhydrite and smectite with minor sulfide phases. The seafloor in the area is covered with a hydrothermal crust which consists of altered basalt, barite, amorphous silica, and sulfides [*Zierenberg et al.,* 1995]. Large areas of the vent field between the chimney ridges are covered with a blue mat-like foliculind ciliate [*Clague et al.,* 2001]. The vent fluids were essentially clear with temperatures up to 300°C. The fluids have been found to be low in chlorinity and metals, with a slightly elevated pH [*Von Damm et al.,* 2004]. Vent fluid samples collected during the 2004 dives were analyzed and found to be the same as those sampled in 2000 and 2002 (K. Von Damm, pers. comm., 2004).

Raman Spectra

Hydrothermal Fluid

The primary purpose of our expedition to Gorda Ridge was to use Raman spectroscopy to detect the various constituents of hydrothermal vent fluid in situ. High-temperature vent fluid was analyzed on two dives. On the first dive, a noncontact optic was used behind a dome window that was not in contact with the hydrothermal fluid; thus some ambient seawater was in the optical path. The focal point was positioned inside the volume of exiting fluid using the ROV manipulator. On the second dive, we used an immersion optic protruding into an open-bottomed box (Figure 2) that was held over the vent to collect the buoyant hydrothermal fluid. In this case, the optic window was immersed in the vent fluid.

The Raman spectrum of seawater is well known and is composed of bands due to the H-O-H bending (~1640 Δcm^{-1} band) and O-H stretching (~3000-3800 Δcm^{-1} region) of the water molecule, and a peak at ~981 Δcm^{-1} due to the sulfate ion. Data in the literature have shown that the stretching bands of the water molecule are affected by both temperature and pressure.

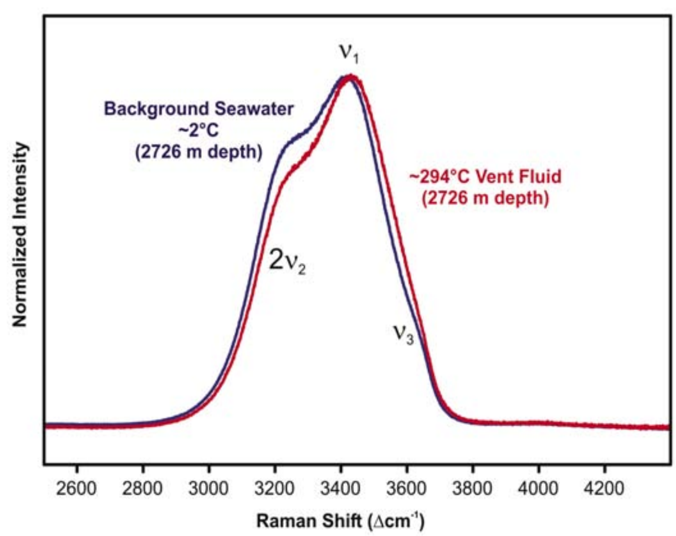

Fig. 3. The Raman spectra of ambient seawater (blue) and 294°C vent fluid (red) acquired using the noncontact optic. Note that the vent fluid spectrum has components from both the 294°C fluid and seawater that is in the optical path.

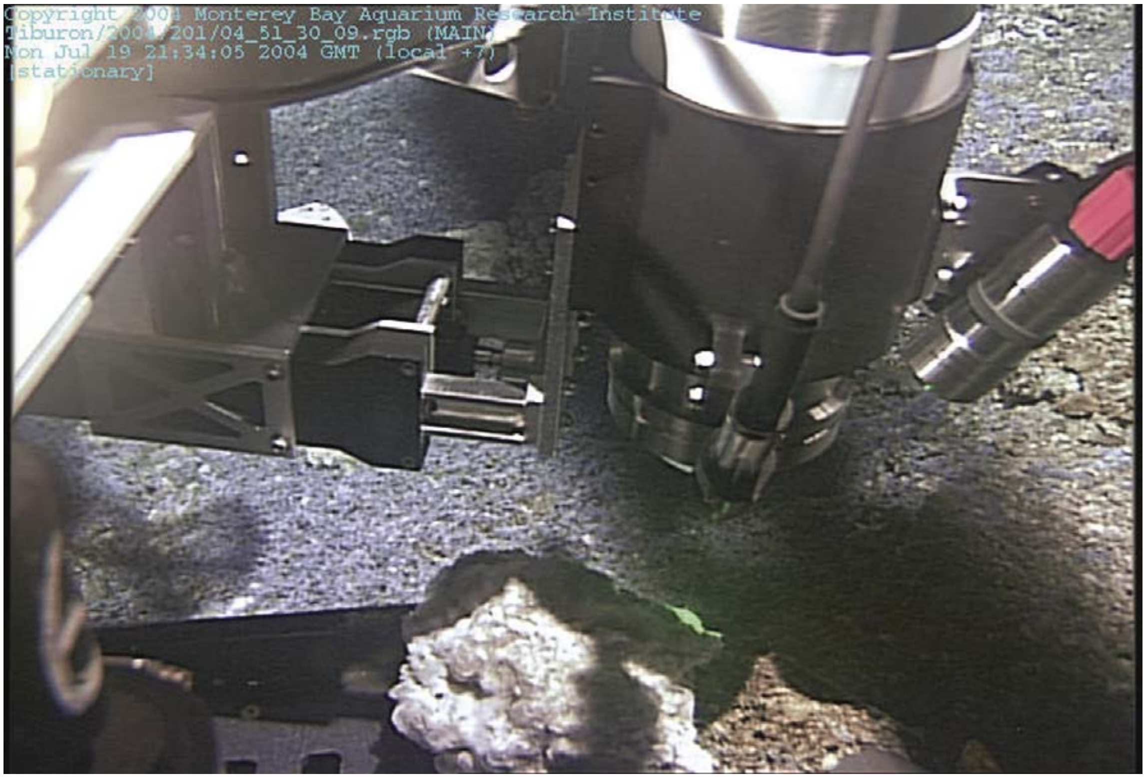

Fig. 4. PUP is used to position the DORISS probe head on a rock sample. The green laser spot can be seen on the upper right of the rock.

We obtained a number of spectra of vent fluid using the two configurations mentioned above. In all cases, we observed changes in the region of the O-H stretching modes of water attributed to the elevated temperature of the hydrothermal fluid. The ratio of the areas of the $2\nu_2$ band to the n1 band decreases as water temperature increases. Figure 3 compares the O-H stretching region of the spectrum of ~2°C ambient seawater to that of ~294°C vent fluid. Note that these spectra were collected using the noncontact optic, and thus the vent fluid spectrum is a combination of the vent fluid being analyzed and ambient seawater in the optical path. When using the immersion optic configuration (Figure 2), we found that the intensity of the Raman spectra decreased over time, because the sapphire pressure window of the optic was immersed in the vent fluid and a light sulfide coating built up on the window. The other major observation was the decrease in or lack of a signal from the sulfate ion since vent fluid is stripped of sulfate in the subseafloor.

Based on previous fluid analyses, the following gas concentrations were expected: CO_2 ~16 mmol/kg, CH_4 ~0.05 mmol/kg, H_2S ~0.06 mmol/kg (M. Lilley, pers. comm., 2004). We were unable to detect peaks characteristic of CO_2, CH_4, or H_2S. This was due to instrument sensitivity, and the difficulty in keeping the immersion optic window free from sulfide coatings.

Minerals

PUP was used to position the DORISS probe head at rock samples on the seafloor (Figure 4). In some cases, chimney material was broken off onto the ROV porch and analyzed there. Two minerals were primarily observed with the DORISS instrument: anhydrite and barite. When analyzing hydrothermal crusts and rubble in the vent field, we detected barite ($BaSO_4$). This mineral was mostly found as thin rinds or veins around darker material that exhibited significant fluorescence. Further analysis of the crust material will begin soon. The chimneys in the Sea Cliff field are primarily anhydrite ($CaSO_4$). Anhydrite is stable at temperatures above ~130°C [*Haymon and Kastner,* 1981] but is soluble in cold seawater. Thus, anhydrite was not observed away from the high-temperature venting. There are two other common calcium sulfate minerals: bassanite ($2CaSO_4 \cdot (H_2O)$) and gypsum ($CaSO_4 \cdot 2(H_2O)$). These three calcium sulfate species can be distinguished by their Raman spectra. The peak positions and peak intensities of the Sea Cliff sample correspond well to anhydrite, and are clearly different from gypsum and bassanite by amounts greater than instrument error (Figure 5).

Bacterial Mats

Bacterial mat spectra were obtained serendipitously in the Sea Cliff Hydrothermal Field while trying to collect spectra from a chimney. Previous laboratory studies of bacterial mat using Raman spectroscopy showed that the bacteria produced elemental sulfur in an S_8 morphology [*Pasteris et al.,* 2001]. In situ spectra collected from Gorda Ridge correspond well to S_8 elemental sulfur.

Conclusions

While in situ Raman spectroscopy is proving to be a valuable geochemical tool, operational and technical challenges remain, particularly when using the tool in hydrothermal vent environments. A new second-generation DORISS is being developed with increased sensitivity, and in a smaller, lighter package for deployment on other deep-submergence vehicles. Improved methods are also being developed to obtain higher-quality spectra of hydrothermal fluids and minerals in situ.

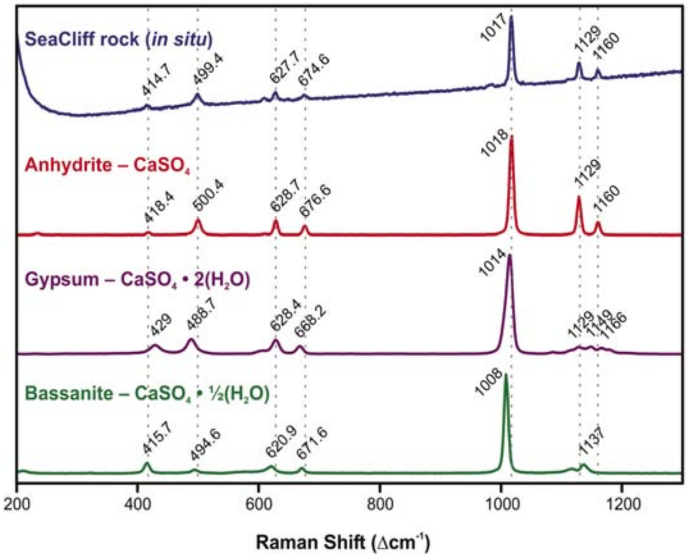

Fig. 5. The Raman spectrum from a Sea Cliff chimney sample is compared to reference spectra of calcium sulfate minerals anhydrite, gypsum, and bassanite. The peak positions (dashed lines) and peak intensities correspond well to anhydrite.

Acknowledgments

We thank the captain and crew of the R/V *Western Flyer,* and the pilots of the ROV *Tiburon.* Funding was provided by the David & Lucile Packard Foundation.

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Mapping the Northern EPR Magmatic System Using Marine EM

Kerry Key, Steven Constable, and James Behrens *(Scripps Institution of Oceanography, La Jolla, CA)*, Graham Heinson *(University of Adelaide, Australia)*, and Chester Weiss *(Sandia National Laboratories, Albuquerque, NM)*

In February 2004, we set sail on the R/V *Roger Revelle* toward 9°N on the East Pacific Rise with plans to conduct the world's largest academic marine electromagnetic (EM) survey as part of an NSF Ridge 2000 funded project (OCE-02-41597). Electrical conductivity—the physical property mapped by EM surveys—is a strong function of temperature and fluid content, whether magma or seawater. Our objectives were to collect enough EM data to spatially characterize the ridge magmatic and hydrothermal systems. To accomplish our goal, we deployed a large array of seafloor EM receivers across the EPR (Figure 1), which served to measure EM fields from two complementary methods:

1. Broadband marine magnetotelluric (MT) method [*Key and Constable,* 2002]. An array of seafloor EM receivers (Figure 2) records natural variations in Earth's electric and magnetic fields for durations of about 7 to 14 days. MT time series are transformed into the frequency domain and used to estimate seafloor impedance responses in the period range of about 20 to 10,000 seconds. Seafloor impedances are then inverted to obtain conductivity estimates from a few hundred meters up to hundreds of kilometers depth. The MT method is preferentially sensitive to conductive, rather than resistive, structure.

2. Marine controlled-source EM (CSEM) sounding. An electric dipole transmitter (Figure 3) is deep towed close to the seafloor to provide a source of EM energy while an array of seafloor EM receivers monitor the spatial character of the electric field attenuation. The amount of attenuation is proportional to the seafloor conductivity and the source-receiver distance. Data collected at source-receiver distances of about 1 to 20 km have sensitivity to structure in the near surface to several kilometers depth. The CSEM method is preferentially sensitive to resistive structure.

Our array of EM receivers consisted of 40 broadband instruments [*Constable et al.,* 1998] that have been developed over the past 10 years at Scripps Institution of Oceanography with ongoing support from the petroleum exploration industry. The continual refinement of this instrumentation has resulted in a highly efficient system that allows deployments to occur as fast as once every 30 to 45 minutes. During the cruise we divided into two teams, each covering 12-hour shifts, and were able to perform deployments and recoveries 24 hours a day.

Since the array of receivers had to remain on the seafloor for at least a week to collect natural source MT data, we concurrently conducted the CSEM experiment, which operates in a higher frequency band than MT. The dual use of the EM receivers for both methods allowed us to collect a record amount of data: a total of 72 deployments yielded 69 sites of MT data and 38 sites of CSEM data. Twenty of the deployments were along a 30 km aperture transect across the Ridge 2000 ISS "bull's eye" at 9°50'N (Northern Line, Figure 1) to image the electrical conductivity structure in the crust and shallow mantle in the vicinity of the ridge axis. Farther south, 40 sites were deployed along a 200 km aperture transect at 9°30'N (Southern Line, Figure 1) to target both crustal and upper mantle conductivity structures. The position of this larger aperture transect was chosen to avoid 3D structure associated with the Lamont seamounts and the Clipperton transform. Twelve additional sites were deployed in a grid along the ridge axis between 9°30'N and 9°36'N. Initial time-series processing of the MT data are yielding MT responses in the period band of about 20 to 10,000 seconds, which is similar to the four-site pilot MT experiment at 9°50'N [*Key and Constable,* 2002].

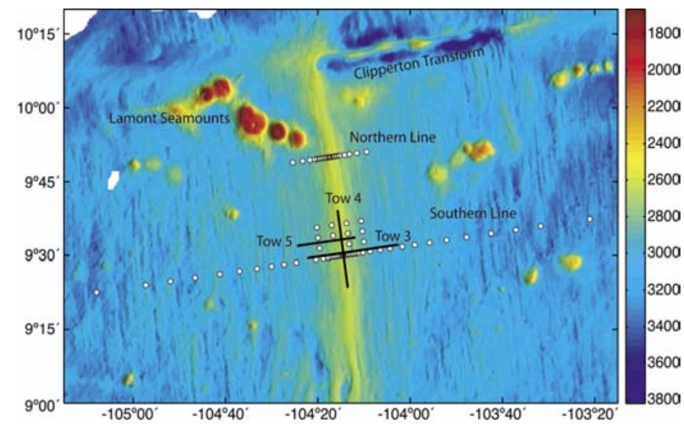

Fig. 1. Bathymetry map showing experiment location on the East Pacific Rise near 9°N. White circles show the locations of the 69 broadband MT/EM sites occupied. Controlled-source EM (CSEM) transmission tows are shown as black lines. During the CSEM tows, all 40 EM receivers occupied the sites along the southern portion of the experiment. Color bar units are meters.

For the CSEM portion of the experiment, we used the newly developed Scripps Undersea EM Source Instrument (SUESI), which was also funded through industrial collaborations (Figure 3). SUESI operates as a deep-towed vehicle and is attached to the ship using a 0.680-inch coaxial cable, which supplies power for the EM transmissions and allows two-way communication with SUESI's onboard systems. During EM transmissions SUESI was flown above the seafloor at 100 m altitude in order to maximize the amount of EM energy diffusing into the ridge. To accomplish this without crashing SUESI into the rugged

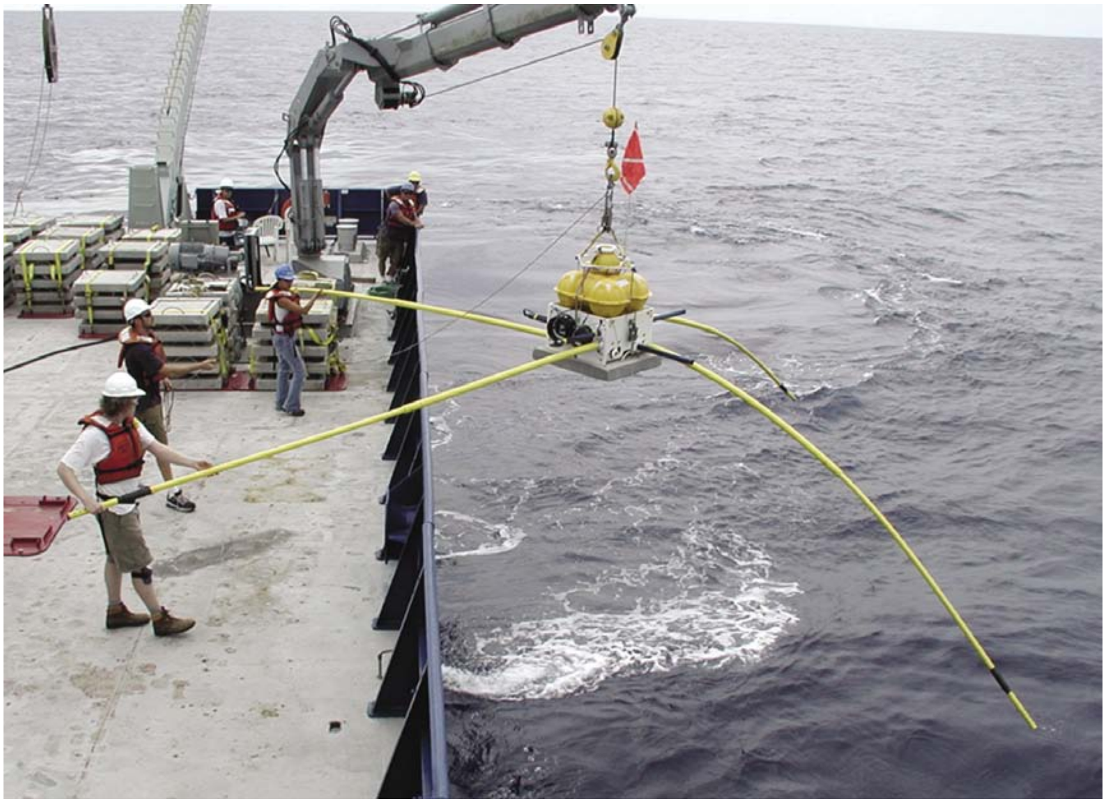

Fig. 2. Broadband marine MT/EM receiver (Constable, 1998) deployment on the R/V *Roger Revelle*. Ag-AgCl electrodes in the end of the 5-m-long yellow arms are used to measure the horizontal components of the seafloor electric field. Horizontal magnetic fields are measured using induction coil magnetometers. A concrete anchor ensures stability on the seafloor.

topography of the seafloor, we used real-time monitoring of pressure and altimeter sensors mounted on SUESI's frame to guide how much cable to pay out or haul in. The strength of an EM transmitter, known as the *dipole moment,* is the product of both the source current and the antenna length. During this experiment SUESI pushed a 200 Ampere current through a 100 m long dipole antenna (which is a long cable terminated with copper electrodes at each end), generating a 20,000 Ampere-m dipole moment. By electronically switching the source current polarity twice every second (i.e., a 2 Hz fundamental square wave transmission), SUESI induced EM fields in the seafloor. The spatial variability of these EM fields, as recorded by the array of EM receivers, is characteristic of the underlying geologic structure.

Engineering delays preparing SUESI, coupled with the scheduling of *Alvin* dives during the first half of February at 9º50'N dictated that our CSEM could only be towed along the southern portion of the EM receiver array near 9º30'N (Figure 1). After two initial attempts, we were able to successfully accomplish 80 km of transmissions during three tows, as shown in Figure 1. Our first choice in towpaths was across the ridge, which would transmit energy through the upper crust to a large number of receivers (Tow 3). Data from this tow should yield a detailed two-dimensional image of the across-ridge conductivity structure associated with the hydrothermal and upper crustal magmatic system. The wide length of this transect should enable us to constrain the lateral extent of the hydrothermal system. Our second towpath (Tow 4) followed the ridge axis, allowing EM fields to diffuse through the crust to receivers on both sides of the ridge axis. Although this configuration may not constrain across-ridge variations as well as Tow 3, it should allow for detection of along-axis conductivity variations and east-west asymmetry of crustal melt accumulations. Left with a contingency day of ship-time before initiating the recovery of the 40 receivers, we decided to collect one more across-axis tow, this time through the middle of the grid of sites around 9º33'N (Tow 5). Near the end of this tow, SUESI operations were terminated when our topside transformer overheated. Although this prematurely ended the CSEM experiment, we were nevertheless pleased to have collected so much data, and this shakedown voyage of our new transmitter left us in a good position for future experiments in 2004 [e.g., *Weitemeyer et al.,* 2004].

Figure 4 shows processed CSEM data for Tow 4 collected at a site on the ridge axis. Both the amplitude and phase data show very little scatter compared to previous ridge CSEM data sets [*Evans et al.,* 1991; *MacGregor et al.,* 2001]. Although the data scatter in the previous surveys was attributed to *geologic* noise from near surface heterogeneity, our data suggest that instrumental issues were the more likely cause of scatter in previous data sets. The 44 hours over which SUESI operated have resulted in about 1300 receiver-hours of CSEM data [compare with 318 receiver-hours in the experiment of *MacGregor et al.,* 2001]. Despite the recent explosion in the use of marine EM to characterize petroleum targets [e.g., *Eidsmo et al.,* 2002], and considering the combination of MT and CSEM data collected, we have probably performed the largest marine EM survey carried out to date. We believe this experiment represents a significant step forward in the state of the art for mid-ocean ridge EM studies and we are excited about the results that will emerge from analyzing this big data set.

For more information, see http://marineemlab.ucsd.edu/Projects/EPR2004.

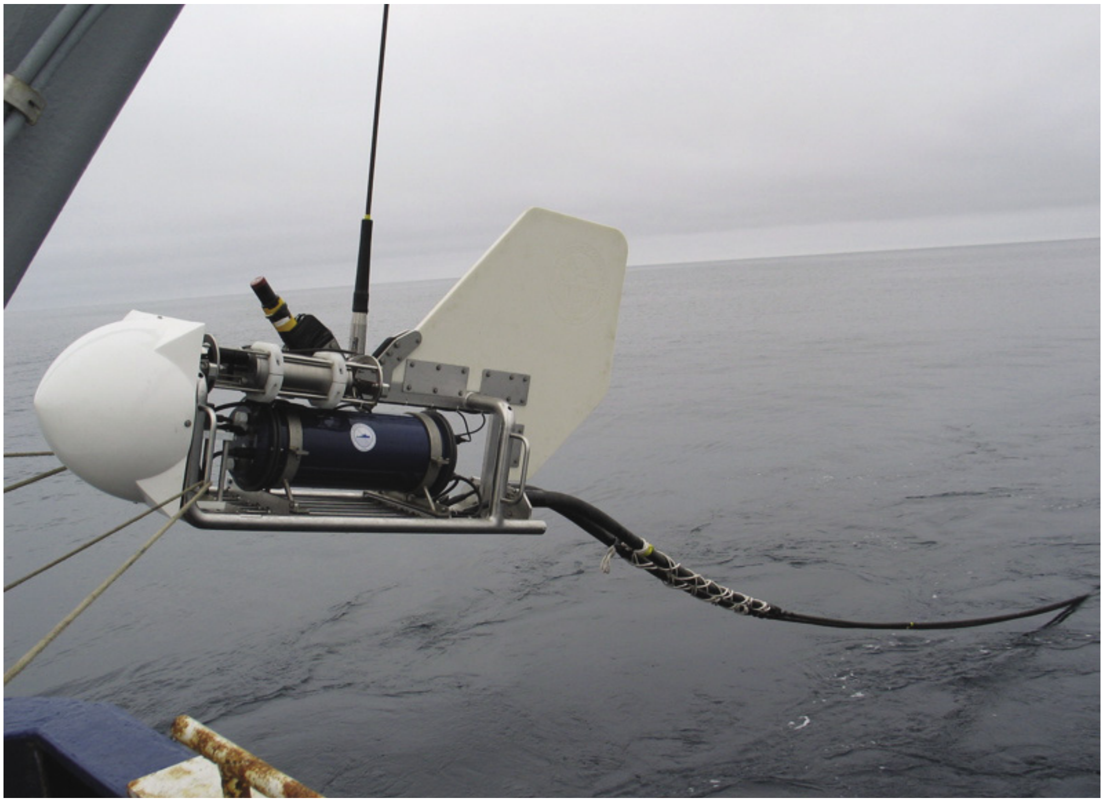

Fig. 3. Scripps Undersea EM Source Instrument (SUESI) used for the CSEM survey. SUESI is capable of transmitting 200 amps over a 200-m-long dipole antenna.

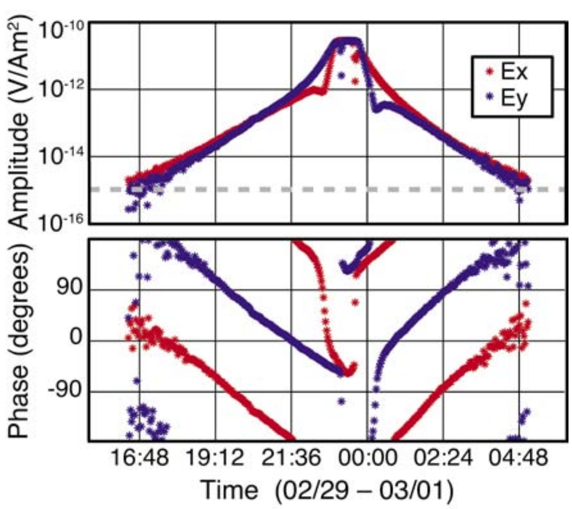

Fig. 4. CSEM data for Tow 4 from an EM receiver located on the ridge axis. The electric field amplitude (top) and phase (bottom) are shown versus time. The dashed grey line shows the corresponding EM receiver noise floor.

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Status Report on the Ridge 2000 Data Management System, RODES

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Maya Tolstoy, *Site Coordinator*

An effective data management scheme is essential for the success of Ridge 2000, both to ensure timely sharing of information to the broader community, to facilitate integration of the broad suite of studies carried out within each Integrated Studies Site, and to enable comparisons between sites. Data management for Ridge 2000 needs to handle diverse and multiresolution data types, as well as serve a user community comprised of specialist and nonspecialist researchers.

To help meet these data sharing needs, we are developing an integrated data management system, which will provide basic cataloging and easy retrieval for data collected as part of the program (www.marine-geo.org/ridge2000). The data system is fully integrated with similar efforts for MARGINS, the disciplinary databases for seismic reflection data, and bathymetry data from the global ridge system (RidgeMBS) and the Southern Oceans (AntarcticMBS). The ultimate aim of our effort is to develop an easy-to-use and content-rich resource to facilitate marine geoscience research throughout the global ocean.

The backbone of the data system is a cruise metadata catalog, which serves basic cruise information, geophysical and sample data inventories, and relevant metadata and navigation. In addition to the metadata, the primary data sets that will be hosted locally include key environmental data of broad relevance (e.g., bathymetry), high-priority-derived data products, and data types for which no web-accessible digital repository currently exists. For data that reside within an existing national repository, data access will be provided by linking to these sites, rather than by duplicating data holdings (e.g., geochemical data in PetDB, deep submergence data at WHOI, hydroacoustic data at PMEL, NOAA).

On the website, three tools are provided for accessing data:

- *Data Link,* a forms-based search page that allows users to query the cruise metadata catalog through a web interface by parameters such as data type, location, principle investigator (PI), cruise name, date, and ports;
- *Create Maps and Grids,* a web-based tool for on-the-fly creation of a bathymetric grid and map for any selected area from our global bathymetry database;
- *GeoMapApp,* a Java application that permits dynamic exploration of multiple colocated data types from a map interface.

More information on these tools and the structure of the data system is provided in *Carbotte et al.* [2004] and at our website.

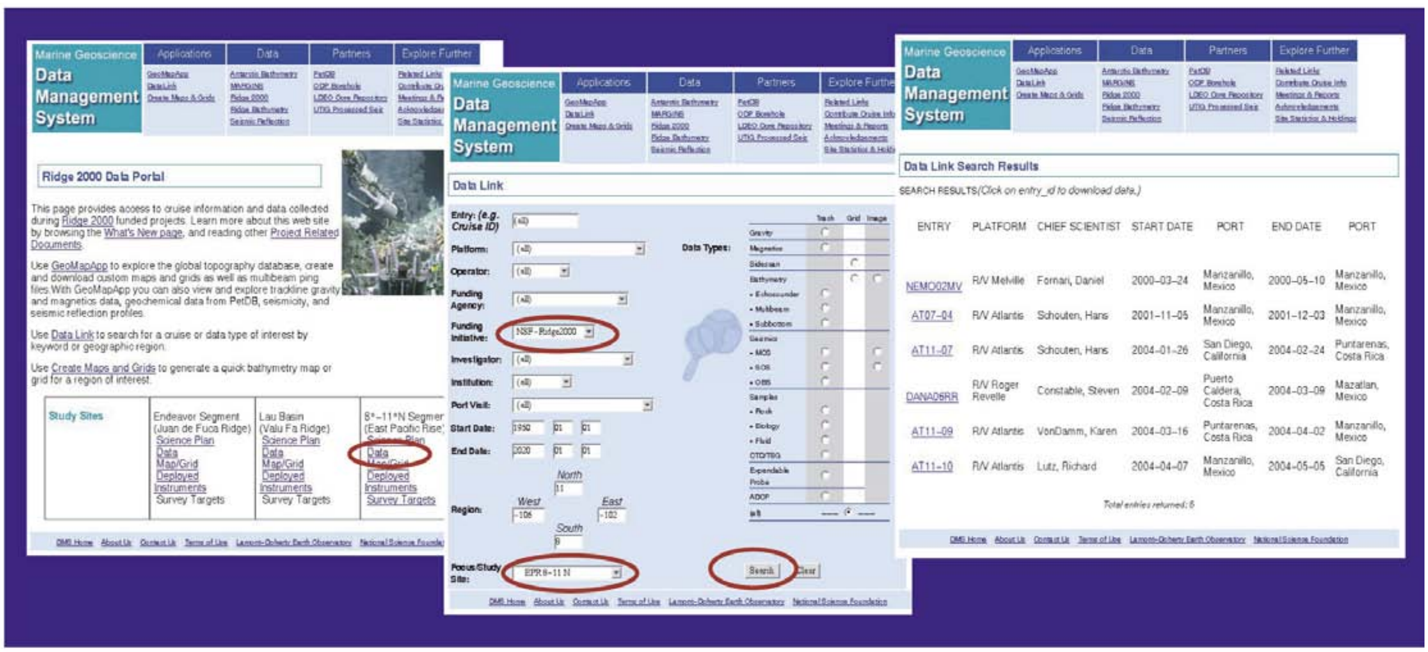

Fig. 1. *(left)* Home page for the Ridge2000 database. *(middle)* Text based search page with search parameters set to find cruises funded under R2K in the EPR ISS. *(right)* Search returns a list of cruises. Further information for each cruise including data and sample inventories are available by clicking on cruise name.

Current data holdings and access

Project Information

The first field programs of the Ridge 2000 program sailed in 2004, as did several expeditions closely related in science goals but not funded under Ridge 2000. Cruise information for many of these field programs have been submitted and are now accessible through the database (Figure 1). For these cruises, complete field parties are available, along with a list of projects associated with each cruise and links to relevant NSF Fastlane award pages. Navigation information is included for the ship, submersibles, and towed instruments (if submitted), as well as sample locations. An inventory of data types collected on the cruise is provided along with the contact person for each data type and links to download data files, if they are available. Data files submitted to the database are held with a proprietary hold unless the PI approves immediate release. Submitted cruise reports, links to cruise/project websites, and links to web pages for information on an instrument type are also included.

Bathymetry

Bathymetry data are of particular importance for ISS studies as they provide an integrating framework for the range of multidisciplinary studies carried out at each site, as well as a fundamental dataset for understanding geological processes. Wide-swath multibeam bathymetry data are available for each ISS, and include ping files and composite grids, as well as published gridded compilations, including the *Zellmer et al.* [2000] grid for the Lau basin and the *Cochran et al.* [1999] and *Macdonald et al.* [1992] grids for the EPR site. Ultrahigh-resolution (2 m) Imagenex bathymetry for the EPR site from *Fornari et al.* [2004] are available, as well as near-bottom high-resolution DSL 120 side-scan sonar and phase bathymetry from Schouten, Tivey, Fornari and colleagues. Over the past year, Ridge 2000 funded V. Ferrini (LDEO/WHOI) to generate composite bathymetry maps from the *Alvin* dive programs in 2004 at the EPR and Endeavour sites. These composite maps are being developed as community data products and will also be served from the database in the coming months.

Site Summary Information

Integrated long-term monitoring studies at the site "bull's eye" are an important component of the science envisioned for all ISSs under the Ridge 2000 program. To facilitate collaboration and optimal deployment of instrumentation, and to ensure lack of interference of deployed experiments, mechanisms to facilitate easy communication are needed. To help support these needs, we will maintain site-specific compilations including dynamic lists of currently deployed instruments at each site, which are automatically updated as new information is submitted. At present, information on vent locations and deployed instruments for the EPR site are served (Figures 1 and 2). As data contribution continues, we will be able to provide similar composite information for the Lau and Endeavour sites.

Data Visualization

GeoMapApp is the primary data visualization tool integrated with the Ridge 2000 data system and currently provides access to bathymetry data for each of the ISSs as well as data available in other databases (seismicity data from PMEL, NOAA; geochemical data from PetDB; trackline gravity–magnetics and topography and regional single-channel seismic data from the Lamont MG&G database). Options are provided for simple data manipulation (e.g., digitizing profiles) and generating custom maps and grids for downloading. GeoMapApp is being developed to enable users to easily import their own data. At present, Excel spreadsheets or ASCII data tables (e.g., from your recent cruise) can be imported through the "Import Data" option, enabling users to explore the relationship of their own data with the other available data. The currently deployed instruments at the EPR site are an available data set under the Import Data option and are shown in Figure 2 plotted on the high-resolution ABE Imagenex bathymetry [*Fornari et al.,* 2004] for the EPR site.

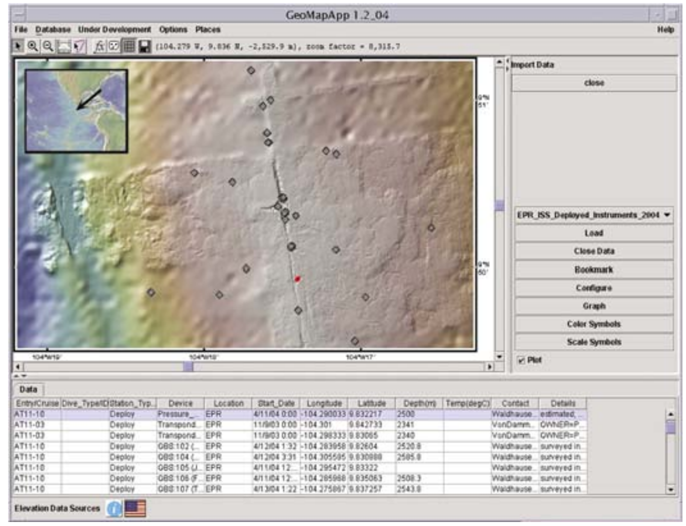

Fig. 2. GeoMapApp interface showing high-resolution Imagenex bathymetry for a portion of the EPR bull's eye site from *Fornari et al.* [2004] merged with lower resolution regional bathymetry of Cochran et al. (1999). Locations of instruments deployed during the 2004 field season and currently on bottom are plotted and can be explored using both the map view and data table.

Needs for community input

Over the coming year we will be actively soliciting contributions of cruise information for other recent programs within the ISSs as well as older historical data. We are seeking cruise reports and field data, as well as the derived data and interpretive products that are often of most use to the broader community. For upcoming field programs in 2005, we ask scientists to use our cruise metadata forms (www.marine-geo.org/data_forms.html), which were tested by expedition scientists in 2004 and were revised in early 2005 based on feedback received from these programs. As per the Ridge 2000 Data Policy, scientists are asked to submit their cruise information, sample inventories, and navigation within 60 days of their expedition, with submission of data files to follow guidelines outlined in the Data Policy (http://www.ridge2000.org/NewR2kSite/about/data_policy.php). The development of the database as a resource for Ridge 2000 science depends on the active involvement of the Ridge 2000 community, both in submitting their cruise information and data, as well as in helping to identify additional needed historical data or derived data products. We are grateful to all who provided cruise information and data over the past year and encourage additional submissions.

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Upcoming Meetings

Joint International Symposia for Subsurface Microbiology and Environmental Biogeochemistry • 14-19 August 2005 • Jackson Hole, Wyoming • Web: www.issm-iseb.org/index.htm

Symposium on 3-D Seismic Reflection Imaging • 8-10 September 2005 • Lamont-Doherty Earth Observatory, Palisades, NY • Contact: John Mutter, jcm@ldeo.columbia.edu

9th International Workshop on Numerical Modeling of Mantle Convection and Lithospheric Dynamics • 8–14 September 2005 • Erice, Italy • Web: www.ingv.it/erice2005 • Abstract deadline: 31 July 2005

Third International Symposium on Hydrothermal Vent and Seep Biology • 12–16 September 2005 • Scripps Institution of Oceanography, La Jolla, California • Web: www.Ridge2000.org

Oceans 2005 • 19–23 September 2005 • Washington, DC • Web: www.oceans2005.org

Geological Society of America Annual Meeting • 16–19 October 2005 • Salt Palace Convention Center, Salt Lake City, Utah • Web: www.geosociety.org/meetings/2005/

Ridge 2000 Community Meeting • 31 October–2 November 2005 • Delta Vancouver Suites, Vancouver, British Columbia • Web: www.Ridge2000.org

American Geophysical Union Fall Meeting • 5–9 December 2005 • Moscone Center West, San Francisco, California • Web: www.agu.org/meetings • Abstract deadline: 8 September 2005 ***(Watch for information on a Ridge 2000 session)***

2006 Ocean Sciences Meeting • 20-24 February 2006 • Honolulu, Hawaii • Web: www.agu.org/meetings/os06/ • Abstract deadline: 20 October 2005

Ridge 2000 Theoretical Institute on Modeling Mid-Ocean Ridge Hydrothermal Processes—Magma to Microbe • Summer 2006 • Details to be announced via www.Ridge2000.org

Moving? Want to join the Ridge 2000 mailing list?

On the Ridge 2000 Web site, you can update your contact information or become a new member of the Ridge 2000 community: **http://www.ridge2000.org**

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