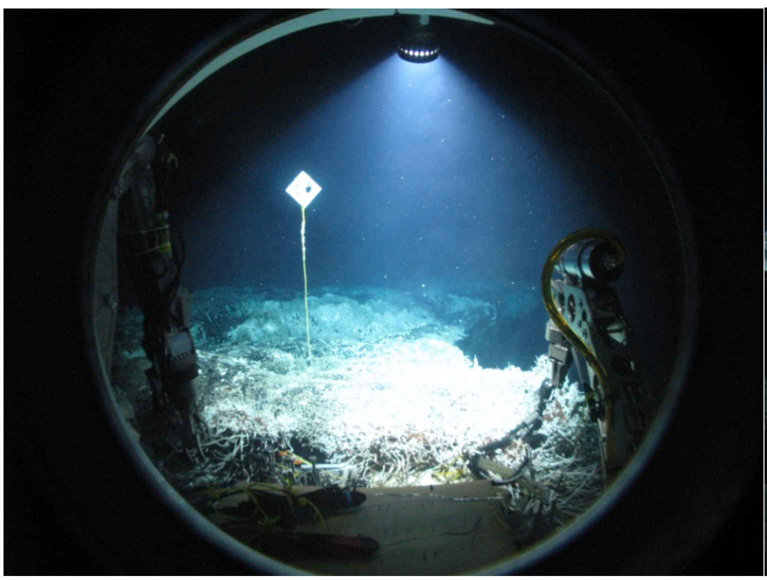
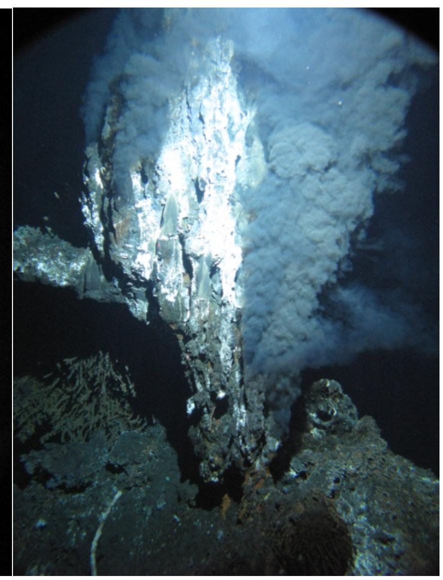
Endeavour-Axial Geochemistry and Ecology Research (EAGER) 2009 Cruise
R/V *Atlantis* – DSV *Alvin* AT15-47

Endeavour Segment and Axial Volcano
Juan de Fuca Ridge, Northeast Pacific Ocean





June 13 – 27, 2009

Chief Scientist

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Project Leaders

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Cruise summary and acknowledgments: This cruise involved 22 scientists from five countries and studied two deep-sea hydrothermal vent sites in the northeastern Pacific Ocean. It was a combination of a research program funded by the National Science Foundation (NSF) to study the Endeavour Segment in Canadian territorial waters and another program funded by the National Oceanic and Atmospheric Administration (NOAA) to continue monitoring activity at Axial Volcano in international waters. Three undergraduate students from the University of Massachusetts Amherst, Harvard University, and the University of Hawaii Hilo participated in the cruise, including a racially underrepresented female, as part of our educational outreach program. A web blog that was updated daily from the ship was used as part of our educational outreach and to date has received over 2,000 hits. We successfully completed 10 of our 13 planned *Alvin* dives with 1 full dive and 2 half dives lost due to poor weather. With *Alvin*, we collected 135 hydrothermal fluid samples, 10 biology samples, 5 sulfide chimney samples of various ages, and 2 basalt rock samples. Three McLane fluid samplers that were deployed for two weeks to a year were recovered, and one at Axial Volcano was replaced with a new sampler that will remain in place until next summer. The *Alvin* and McLane fluid and sulfide chimney samples will be used for microbiological and geochemical analyses and the development of a quantitative biogeochemical model of fluid alteration at Endeavour and Axial Volcano. We also deployed and recovered at resistivity-temperature probe after 2 weeks at the Dante sulfide structure in the Main Endeavour Field for new instrument development and collected black smoker temperature and fluid flow rate measurements for flux modeling. Six people, including 2 graduate students and 2 post-doctoral researchers, made their first dive in *Alvin*.

Other shipboard operations included five vertical CTD casts over Axial Volcano and the Main Endeavour Field, four tow-yo CTD casts throughout the Endeavour Segment, and one background seawater vertical cast. We also recovered and redeployed four hydrophones and two seismometers at Axial Volcano.

We are very grateful to the crews of the *Atlantis* and *Alvin* for their hard work and professionalism, and specifically to the captain of the *Atlantis*, A.D. Colburn, and the *Alvin* Expedition Leader, Bruce Strickrott, for making this cruise a success.

AT15-47 Endeavour-Axial Geochemistry and Ecology Research (EAGER) 2009 Program to the Endeavour Segment and Axial Volcano on the Juan de Fuca Ridge, Northeast Pacific Ocean

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AT15-47 Personnel

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James F. Holden	Chief scientist
Helene C. Ver Eecke	Graduate student
Samantha L. Zelin	Graduate student
Sabrina Parise	Undergraduate student
University of Washington	
David A. Butterfield	Project leader
Eric Olsen	Oceanographer
Kevin Roe	Oceanographer
Hakon Dahle	Scientist
Rika Andersen	Graduate student
Keith Grochow	Graduate student
Sanjoy Som	Graduate student
Alden Denny	Scientist
Oregon State University	
Kerry McPhail	Scientist
Lee Evans	Oceanographer
Pacific Marine Environmental Laboratory, NOAA	
Matt Fowler	Oceanographer (Newport, OR)
Su Gao	Intern (Harvard University)
Brian Yannutz	Intern (Univ. of Hawaii Hilo)
Georgia Institute of Technology	
Leonid Germanovich	Scientist
University of Bristol	
Vyllinniskii Cameron	Scientist
University of Victoria	
Annie Bourbonnais	Graduate student
Candice St. Germain	Graduate student
University of Ottawa	
John Jamieson	Graduate student
Captain *Atlantis*	A.D. Colburn
***Alvin* Crew**	
Bruce W. Strickrott	Expedition leader
Mark O. Spear	Pilot
Sean Kelley	Pilot
David Walters	Pilot-in-training
Korey Verhein	Pilot-in-training
Mike Skowronski	Pilot-in-training
Jeffrey McDonald	Pilot-in-training
Anton Zafereo	*Alvin* technician
Lane Abrams	*Alvin* technician
Christina Fournier	*Alvin* assistant

SUMMARY OF CRUISE OBJECTIVES AND ACCOMPLISHMENTS:

1.1 Geomicrobiology and Fluid Chemistry of Diffuse Hydrothermal Fluids (Holden (UMass), Butterfield (UW), Lilley (UW))

The goal of this study was to determine whether variations in environmental chemistry dictate which type of microorganisms will grow within a specific niche, and then quantitatively estimate the biogenic impact of these organisms on that environment. This will be done by determining the distribution and abundances of specific groups of organisms using culture-based and molecular approaches. Particular attention was given to methanogens and hyperthermophilic autotrophic iron reducers and sulfur-reducing heterotrophs. Low-temperature, diffuse hydrothermal fluid samples were collected and co-localized with high-temperature fluids to estimate the degree of chemical alteration within the subsurface between the high-temperature end-member fluid and the diffuse fluid. These co-localized fluids were collected at two sites at Axial Volcano (ASHES, International District) and at eight sites along the Endeavour Segment (4 Main Endeavour Field, 4 High Rise). We also recovered two McLane fluid samplers from basalt-hosted diffuse venting at Easter Island in the Main Endeavour Field and Marker 33 at Axial Volcano that will provide information on fluid chemistry variability over time. A third sampler was deployed at two sites at Endeavour for two weeks for high frequency sampling of diffuse fluids. All of these fluid chemistry data will constrain the types of microbial processes that may occur. At the Endeavour Segment and Axial Volcano, a total of 135 hydrothermal fluid samples were collected: 100 Hydrothermal Fluid Sampler samples (34 filtered, 47 unfiltered, 19 sterivex filters), 8 titanium major fluid samples, and 27 gas-tight fluid samples. These were used for gas, major ion, and pH analyses; culturing of microorganisms; and molecular analyses.

1.2 Microbe-Mineral-Fluid Interactions within Hydrothermal Sulfide Deposits (Holden (UMass), Kelley (UW), Hannington (UOttawa))

The goal of this project was similar to the previous project in that it sought to determine how the combination of fluid chemistry and sulfide chimney mineralogy shape microbial community composition within hydrothermal sulfide chimneys. This will be done by examining the types, distributions, and abundances of various groups of microorganisms within sulfide samples using culture-based, molecular, and microscopic methods with particular attention given to hyperthermophilic iron reducers, methanogens, and sulfur-reducing heterotrophs. Two actively venting and morphologically varied sulfide chimneys were collected, and hydrothermal fluid samples were collected from the vent orifice that produced the sulfide following sampling. The wurtzite-sphalerite rich region and the exterior of these sulfides were separated, removed, and divided for quantitative hyperthermophile culturing; fluorescence in-situ hybridization microscopy; 16S rRNA nucleotide sequencing; petrology; and electron microprobe and trace metal analysis; and Mössbauer, TES, FTIR and synchrotron spectroscopies.

Sulfide samples recovered during the cruise have been sampled, archived, and documented through digital imagery and hand sample analyses. A subset of sulfide samples that were subsampled for co-registered detailed microbiological studies and vent fluid analyses have been processed for major and trace element geochemical analyses. A subset of samples was also provided to Dr. Mark Hannington, University of Ottawa, for incorporation into their on-going studies of sulfur isotopes and exploration of chimney dating. This work is the focus of a Ph.D. student at the University of Ottawa. Sulfide samples have also been processes for petrographic analyses and delivery of sections is anticipated in 1-2 months. During this next year, representative samples will be analyzed petrographically under transmitted and reflected light for characterization of petrogenesis, interpretation of vent chimney formation, and mineralogical characterization of the mincroenvironments where biofilm formation takes place.

1.3 Axial Volcano Hydrothermal Vent Monitoring (Butterfield (UW/NOAA))

NOAA's Pacific Marine Environmental Laboratory (PMEL) has been studying Axial Volcano under the New Millennium Observatory (NeMO) project since 1998, the year of a significant volcanic eruption in the southeast caldera and southern rift zone. The goals of this program (funded primarily by the NOAA/PMEL Vents program) are to follow the temporal evolution of the volcano and associated hydrothermal systems through an entire cycle from eruption to eruption, and to study in detail the links between microbial community structures and the chemical environment. In the eleven years of the project, we have re-sampled many vent sites for chemistry and microbiology nearly every year. Dr. Julie Huber (MBL) and graduate student Andrew Opatkiewicz (UW) are both involved in detailed molecular studies of DNA collected from diffuse vet sites at Axial Volcano. Opatkiewicz is using the tRFLP technique to compare the most abundant phylotypes from a wide range of vent sites over time and comparing the microbial community structures with fluid chemistry using statistical techniques. For 2009, the primary goals of the project were to re-sample selected vent sites from ASHES, Marker 113, International District, Marker 33, and Cloud. Particular attention was given to Marker 113 with intensive sampling at three sites within the region. We accomplished all of our sampling goals.

As part of the time-series study, we have monitored several different vents (high- and low-temperature) using McLane Remote Access Samplers (RAS) and temperature recorders. In 2008, we deployed a RAS with a PVC cover to focus warm fluid venting from the tubeworm-filled crack at Marker 33. This sampler was recovered and replaced with a similar RAS to be recovered in 2010.

1.4 Resistivity-temperature probe deployment (Lilley (UW))

A short-term installation of a Resistivity-Temperature probe from the laboratory of Marv Lilley (University of Washington) was accomplished during this program. An Eh measuring sensor provided by Ko-ichi Nakamura of the National Institute of Advanced Industrial Science and Technology of Japan was also attached. The instrument was deployed in a black smoker vent, high on the Dante structure of the Main Endeavour Field, where it remained for approximately 8 days. At installation, a temperature of 336.1°C was measured. Resistivity and temperature were measured every 15 seconds (data stored internally) and a value for Eh was logged every 2 minutes. Resistivity (measured as a voltage) is the reciprocal of conductivity which is used as direct proxy for chloride content in vent fluids. Discrete fluid samples were collected at insertion and removal for chloride calibration. Eh readings give some measure of the content of electrochemically reduced chemical species in the fluid. Previous studies of resistivity and temperature have shown temporal effects at the scale of tidal oscillation; however, this represents one of the first opportunities to collect data at higher frequency over a time span of 7-8 days in vents on the Endeavour segment.

1.5 Age-dating and long-term accumulation rates of hydrothermal sulfide deposits (Hannington (UOttawa))

The goals of this project were to determine the age of seafloor hydrothermal sulfide deposits, and from those ages, examine the rate and episodicity of sulfide accumulation on the seafloor. This was accomplished by collecting a range of sulfide samples from the Endeavour Field. Samples were collected with an emphasis on older, 'extinct' sulfides, distal to sites of active venting. These samples were collected in order to constrain a minimum age of the vent field by determining the ages of earlier, now-extinct vent sites. 'Old' samples were targeted based on degree of sulfide surface oxidation and proximity to active venting. Younger samples, from inactive spires and talus from vent structures, were also sampled, in order to construct an age spectrum and growth history of the vent field. Age dates for samples are determined using U-Th disequilibrium techniques. ^{226}Ra is concentrated in barite, a common hydrothermal mineral that precipitates along with sulfide on the seafloor. The decay of ^{226}Ra (half-life of 1,600 years) results in a decrease in the $^{226}Ra/Ba$ ratio within barite relative to an initial ratio. Initial ratios are thought to remain constant over time and can be determined by measuring the $^{226}Ra/Ba$ ratio of sulfide samples from active vents. This technique is effective for dating samples between 500 and 15,000 years. Comparisons between the minimum age of the vent field and estimates of accumulation rates based on modern observations, as well as fluid and heat fluxes, can be used to determine the episodicity of hydrothermal venting over the life-time of the vent field. Three extinct sulfides and 3 active sulfide were collected during this cruise. These samples will be integrated with a larger sample set collected on previous cruises, to extend the spatial and temporal coverage of the Endeavour vent field.

1.6 Fluid fluxes from black smokers and diffuse vents (Germanovich (GaTech))

A new flow meter design was tested at several high-temperature and diffuse fluid vent sites at Endeavour and Axial Volcano to model fluid an heat fluxes from these systems.

1.7 Deep sea vent organisms as a source of medicinally relevant small molecule natural products (McPhail, Zabriskie (OSU))

The overarching goal of this project is to evaluate deep-sea vent organisms as a source of unprecedented small molecule natural products (secondary metabolites) with medicinally relevant properties using a diversity-based strategy integrating microscale chemical and biological profiling. Elucidation of new chemotypes will demonstrate the natural product biosynthetic potential of deep vent organisms and may provide medicinally-relevant chemical and genetic templates for diversity-oriented chemical synthesis, combinatorial biosynthesis, and metagenomic mining for additional natural products belonging to new structure classes. Structurally complex natural products from diverse biological sources continue to be a critical source of lead compounds for drug development and molecular tools to define new cellular targets for rational drug design. Chemical diversity directly correlates with biological diversity, thus phylogenetically unique organisms from rare or extreme ecosystems are rational sources of novel chemotypes with important biological activities.

Therefore, collections of microbial mats and invertebrates will be subjected to chemical extraction with organic and aqueous solvents. These organic and aqueous extracts will be crudely fractionated (by vacuum liquid chromatography) before being subjected to a suite of biological *assays* to test for activity against human cancer cell lines, and eukaryotic (e.g. malarial and trypanosomal parasites) and prokaryotic (e.g. *Mycobacterium tuberculosis*, *Staphylococcus aureus* and *Escherichia coli*) microbial pathogens. Biologically active crude fractions will be subjected to bioassay-guided fractionation using solid phase extraction and HPLC to obtain pure active compounds. These fractionations will also be guided by chemical profiling using mass spectrometry (LC-MS) and capillary microflow nuclear magnetic resonance (NMR) spectroscopy. Molecular structure elucidation of new compounds will be carried out by NMR spectroscopy using either a capillary microflow probe or a 1 mm cryogenic probe on 300, 600 or 700 MHz spectrometers available at OSU. This project will be the focus of OSU College of Pharmacy Ph.D. graduate student Christopher Thornburg.

In general, biological samples obtained from five dives were sorted according to species and immediately frozen (-70 °C) in 1 gallon Ziplock bags, or 100 mL Whirl-Pak bags, depending on sample size. Large collections were only partially sorted, with unsorted material being frozen in a "mixed" bag. In summary, four samples of tube worms (*Ridgeia piscesae*), six samples of bacterial mat (five white and one "peach") mostly associated with the tube worms, one sample of blue protozoan mat, two samples of palm worms (*Paralvinella palmiformis*), one sample of "pandorae" worms (*P. pandorae*), three samples of limpets (*Lepetodrilus fucensis*), one combined sample of scale worms of several species, and three mixed 1 gallon bags were collected.

1.8 Nickel stable isotopes in hydrothermal vent systems (Cameron/Vance (UBristol)), Butterfield (UW/NOAA)

Deep ocean hydrothermal systems are vital to the geochemical cycling of various elements. Vent fluids are typically enriched in trace metals, many of which are essential for the growth and survival of existent microbial communities. However, the biogeochemical interactions directly effecting most trace metals are not well understood or characterized. The objective of this project was to collect a range of hydrothermal samples and seawater specifically to investigate nickel stable isotopes in vent environments. Seawater, low and high temperature vent fluids, and chimney samples were collected from various sites at the Main Endeavor Field and Axial Volcano. Nickel is absolutely essential to methanogens, which dominate most modern hydrothermal vent systems. Additionally, methanogens and vent environments were possibly key to the evolution of life on the early Earth. Recently, we have demonstrated the biological fractionation of nickel stable isotopes by methanogens, with the largest fractionation being produced by a hyperthermophile (*M. jannaschii*). In contrast, terrestrial abiotic materials show relatively insignificant variations in nickel isotopic composition. These novel experiments suggest a potential utility of nickel isotopes as a biomarker and geochemical tracer, concepts which may be borne out by detailed analyses of the samples collected on this cruise and from other environments.

1.9 Viral and microbial metagenomics from diffuse fluids (Baross (UW))

The objective of this project was to collect large volume fluid samples for studies of viral ecology and evolution in hydrothermal vent ecosystems. Little is known about what viruses are present in vent ecosystems, how related they are to other marine viruses, and how they impact the evolution of vent microbes through horizontal gene transfer. To address these questions, we plan to conduct a metagenomic analysis of vent viruses using 454 pyrosequencing. Fluid for this project was obtained via a barrel sampler on a large elevator to collect approximately 200 liters of low-temperature diffuse fluids for a metagenomic analysis of the viruses inhabiting the vent ecosystem. These fluids were concentrated to about 300 ml on board the ship and frozen for later DNA and RNA extraction. Samples were also preserved for counting and for TEM imaging as well as for infection of cultures enriched from fluid samples collected during the cruise. Metagenomic analysis of the viral concentrates as well as the microbial sample filtered through Steripaks prior to concentration will allow for a comparison of the gene pool present in the microbial and viral communities at vents, and potentially give an indication of the nature of horizontal gene transfer between these gene pools. This project was funded by the National Science Foundation's Graduate Research Fellowship program and by a grant to the Carnegie Institution for Science from the NASA Astrobiology Institute. 454 sequencing of the virome will be conducted as part of the Marine Phage, Virus, & Virome Sequencing Project funded by the Gordon & Betty Moore Foundation and the Broad Institute.

1.10 Age Dating of Extinct and Active Hydrothermal Sulfide Deposits (Hannington (UOttawa))

A sampling program was performed to collect active and extinct sulfides of various ages from the Main and Mothra vent fields of the Endeavour Segment. By dating the sulfides, a time series for vent field-scale growth can be established. Hydrothermal barite within the sulfides will be dated with a novel geochronological technique using uranium series disequilibrium to determine the growth history and accumulation rates of the Endeavour hydrothermal field. Age dates are calculated by measuring the ratio of ^{226}Ra-to-Ba in a barite sample. Over time, the ^{226}Ra/Ba ratio decreases, due to radioactive decay of ^{226}Ra (1,600 year half-life). If the initial ^{226}Ra/Ba ratio of a sample is known, then the decrease in activity of ^{226}Ra in a sample will correspond to the age of the sample. Initial ^{226}Ra/Ba ratios can be determined by measuring the ratios in barite from active chimneys. This technique is limited by the half-life of ^{226}Ra to samples ranging in age between 500 and 15,000 years. This time interval is ideal to evaluate the lifespan of vent fields, which are thought to exist over 1,000s to

10,000s of years. Fourteen sulfide samples were collected from Mothra, Main, and Sasquatch vent fields. These were cataloged, described and photographed (see section 4.0). Some of the samples will be archived at the University of Washington. The rest will be analyzed (mineralogy, whole-rock geochemistry, and ^{226}Ra activity) at the University of Ottawa.

1.11 Microbially-Mediated Nitrogen Cycling in Diffuse Hydrothermal Fluids (Juniper (UVic), Butterfield (UW/NOAA))

The goal of this project was to study microbially-mediated nitrogen cycling in hydrothermal vents using a combination of isotopic and microbial molecular ecology methods. The nitrogen cycle in hydrothermal vents is poorly understood, especially the reactions involving bioavailable (i.e., fixed) nitrogen. The isotopic composition of dissolved inorganic nitrogen will be analyzed, which will inform us about potential nitrogen cycle transformations, and denitrification rates will be measure in diffuse hydrothermal fluids using ^{15}N incubation techniques. The microbial communities mediating nitrogen cycle reactions will be determined using 16S rRNA sequencing functional gene analysis. Hydrothermal fluid samples were preserved from high and low temperature fluids for nutrient and nitrogen isotope analyses. DNA for the molecular analyses will come from the sterivex samples collected by Julie Huber at MBL.

1.12 Tubeworm diversity (Tunnicliffe (UVic))

Ridgeia piscesae tubeworms were collected from fluids containing high and low concentrations of hydrogen sulfide to determine the physiological differences within this species as a result of available energy. Long, slender tubeworms predominate in low sulfide environments while short, fat tubeworms prevail in high sulfide environments. Grab samples were collected concomitant with fluid samples to correlate fluid chemistry with animal physiology.

1.13 Education and Public Outreach (Zelin/Holden (UMass))

A graduate student from the University of Massachusetts Amherst (Zelin) maintained a web blog that was updated at least daily (http://eager2009.wordpress.com). More specifically, the blog posts included information about the daily Alvin dives, how science is performed on a research vessel, and how the ship is operated by the crew. Information about the blog was posted on the InterRIDGE web site and received over 2000 hits while we were at sea. Following the cruise, the information collected is being pulled together to form lesson plans and small teaching modules for K-12 teachers throughout the U.S. and the world to implement in their classrooms. It will include lessons on environmental microbiology and the influence of environmental factors on the distribution of microbes by having students create Winogradsky columns in the classroom. The goal is to excite students about non-medical microbiology and life in extreme environments. Ms. Zelin is working with Liz Goehring in the RIDGE 2000 Education and Outreach Office to develop these lesson plans.

2.0 Dive Summaries

Atlantis left Astoria, Oregon at 0800 local time on June 13 and steamed towards the Endeavour Segment hydrothermal vent field. We arrived early in the morning on the 14th and immediately commenced our dive series. After four dives at the Endeavour Segment, we transited to Axial Volcano for an additional four dives before returning to Endeavour to complete our dive program. A summary of *Alvin* dive operations is provided in Table 1. Summaries fluid, biology, and rock samples collected by *Alvin* are available in Tables A1 through A7. A summary of CTD water samples is available in Table A8. Our final dive was on June 26 and we arrived in Seattle in the evening on June 27.

Table 1. Dive participants and locations

Dive #	Date	Pilot	Port Observer	Stbd Observer	Location
4514	14 June 09	Sean Kelley	Lane Abrams	Matt Fowler	MEF
4515	15 June 09	Bruce Strickrott	Dave Butterfield	Jim Holden	High Rise
4516	15 June 09	Bruce Strickrott	Dave Butterfield	Jim Holden	High Rise
4517	16 June 09	Mark Spear	Rika Anderson	Candice St. Germain	MEF
4518	17 June 09	Sean Kelley	Eric Olson	Leonid Germanovich	MEF
4519	18 June 09	Bruce Strickrott	Kevin Roe	Dave Walters (PIT)	ASHES
4520	19 June 09	Mark Spear	Dave Butterfield	Kerry McPhail	Mk 113
4521	20 June 09	Sean Kelley	Annie Bourbonnais	Sanjoy Som	Mk 33/Cloud
4522	21 June 09	Bruce Strickrott	Dave Butterfield	Vyll Cameron	Int. District
4523	22 June 09	Mark Spear	Dave Butterfield	Hakon Dahle	MEF
4524	23 June 09	Sean Kelley	Jim Holden	Jeff McDonald (PIT)	Mothra
4525	25 June 09	Mark Spear	John Jamieson	Keith Grochow	MEF
4526	26 June 09	Bruce Strickrott	Jim Holden	Helene Ver Eecke	High Rise

2.1 Dive 4514: Main Endeavour Field (engineering dive) **June 14, 2009**

Pilot: Sean Kelley
Port Observer: Lane Abrams
Starboard Observer: Matt Fowler

Primary science objectives: 1) Release the RAS mooring at Lobo, 2) major and gas-tight fluid sampling and temperature measurements of diffuse fluids where the RAS was located, and 3) photograph the region around the Lobo diffuse vent site.

Primary engineering objectives: 1) Perform propulsion energy consumption measurements, 2) perform VB pumping energy consumption measurements, 3) operate the new Sonordyne Ranger USBL system, and 4) test the LinkQuest NavQuest Micro 600 Doppler velocity log.

Sample summary: 2 major fluid samples, 2 gas-tight fluid samples, and recovered the RAS mooring.

Dive Summary:

This was primarily an *Alvin* Group engineering dive and was conducted prior to deployment of transponder network so we had poor navigation aboard while on this dive. *Alvin* was launched at 1500 UTC and reached bottom around 1620 on top of the wall located west of the Lobo Vent site. We drove east to the RAS mooring located at Lobo Vent following the RAS homing beacon. When we arrived at the mooring at 1650, we turned the submarine until we were facing heading 256° to more easily access the RAS intake located in the diffuse vent at the mooring site. We first photographed everything then measured temperatures of 4.0-6.2°C around the RAS intake and 2.5°C with the major sampler ICL temperature sensor. We took a major sample pair at 1657 followed by two gas tight samples at 1700 and 1704. We concluded our mission at Lobo by releasing the RAS mooring. It took longer to release RAS mooring than intended because the release line attached to the pull-pin was tangled with the bridle below the RAS frame. We initially approached the mooring facing SSW (heading 187°) but had to maneuver until we were facing NNE (heading 13°) in order to access the tangled pull-pin release line. RAS was released at 1726. The replacement RAS was deployed with release line rubber banded to mooring line to prevent similar difficulties with the RAS recovery next year. This concluded the science portion of the dive, we then began conducting the engineering tests described above.

We began by setting navigation to the only known position, the location of the RAS, then placed a homing beacon on a 2-3 m mooring as a starting point and proceeded navigation system testing and performance testing of *Alvin*'s propulsion plant. We proceeded in a straight line running on various thrusters and then reversed our course and continued thruster testing, proceeding up and down and tested turning *Alvin* in tight circles to the left and right to measure battery consumption rates. We tested VB power consumption rates by pumping water into and out of the VB system. At the conclusion of engineering testing we had approximately 30 minutes of batteries left so we proceeded to Hulk Vent site, but had to surface upon our arrival.

2.2 Dive 4515: High Rise Field **June 15, 2009**

Pilot: Bruce Strickrott
Port Observer: Dave Butterfield
Starboard Observer: Jim Holden

Primary objectives: The primary purpose of this dive was to 1) survey the High Rise vent field for future sampling and 2) collect high and low temperature gas tight and HFS fluid samples from as many structures as possible.

Sample summary: The dive was cancelled by 100 m depth due to a ground in the HFS fluid sampler.

Dive Summary:

Alvin was launched at 1500 UTC. Shortly after immersion in the water, a ground was detected in the HFS fluid sampler that was large enough to prevent its use on the seafloor. Thirty minutes into the dive, we decided to return to the surface to attempt to repair the ground on the sampler. The sub was back on deck by 1600.

2.3 Dive 4516: High Rise Field (repetitive dive) **June 15, 2009**

Pilot: Bruce Strickrott
Port Observer: Dave Butterfield
Starboard Observer: Jim Holden

Primary objectives: The primary purpose of this dive was to 1) survey the High Rise vent field for future sampling and 2) collect high and low temperature gas tight, major, and HFS fluid samples from as many structures as possible.

Sample summary: 4 majors and 3 gas tight samples.

Dive Summary:

Alvin was launched again at 1730 UTC. Again, shortly after immersion we detected the same ground fault in the HFS sampler rendering it inoperative for the remainder of the dive. We decided to continue with the dive using only major and gas tight fluid samplers. Our original dive target was approximately 100 m east of Godzilla; however, a strong SW current near the bottom forced us to drive north in the water column and we landed on the bottom at 1848 north of Godzilla (x:8400 y:5775 d:2,190 m). We headed south and climbed up the west wall of the horst on which High Rise resides and immediately arrived at Godzilla and Bambi (Fig. 2.3.1). After circling the structure, we parked at 1928 at a very vigorously venting black smoker (Fig. 2.3.2) 22.1 m high on the NW face of the structure (x:5769, y:8313, d:2,139 m, h:127°). We were approximately 4-5 m below the top of the structure. The orifice of the venting was approximately 10 cm and fluids were exiting it at high velocity. Using the high temperature probe, the temperature of the fluid was 349.1°C. At 1933, we used the Germanovich flow meter to measure the velocity of the flow while recording the meter using the 3-chip camera on the starboard arm and a hand-held camera inside the submarine. At 1945, we collected a gas tight fluid sample using the orange-black sampler. At 1954, we collected more fluid using the left side of the red major sampler. There was no ICL measurement. We were concerned that the first gas tight sample did not work properly; therefore, at 1957 we collected a second gas tight fluid sample using the unmarked sampler.

We then left the site and headed due west to the west edge of the horst to the Three Sisters area where there was extensive diffuse venting and some black smokers and followed the edge of the horst south. There was extensive diffuse venting all along the western wall. At 2029, we rose up the wall and up the Park Place structure at the edge of the wall and stopped at a smoker (Fig. 2.3.3) that was at an altitude of 14.2 m again about 3-4 m below the pinnacle of the structure (x:5736, y:8258, d:2,149 m, h:125°). Using the high temperature probe, the temperature of the smoker fluid was 332.3°C. At 2033, we collected fluid using the right half of the red major sampler, and at 2035 we collected a gas tight fluid sample using the green sampler. At 2040, we took another flow meter measurement as described above. The size of the orifice was approximately 3-4 cm and the flow rate was not a vigorous as what we saw at Godzilla. As we left Park Place, we took a full vertical profile of the structure from its top to its base along its western face.

We then continued south along the west wall of the horst where we again saw extensive diffuse venting along the wall. We rose up the wall and up the Baltic structure (Fig. 2.3.4) where we stopped at a smoker at 2112 that was 14.2 m above the bottom (x:5743, y:8211, d:2,147 m, h:095°). The temperature of the smoker fluid was 333.1°C. At 2119, we collected fluid using the left half of the yellow major fluid sampler. From Baltic, we headed almost due west down the west face of the horst across the valley towards the Ventnor vent structure on the opposite side of the valley. Along the way at 2130, we crossed over Blue Moon vent (x:5671, y:8201, d, 2,171 m, alt. 6.6 m, h:180°) where there was no apparent black smokers but extensive diffuse venting and a large spire covered with palm worms (Fig. 2.3.5).

At 2140, we arrived at Ventnor vent and found Marker 1M on the west side of the structure, the only marker we found in the entire field (x:5604, y:8196, h:065°). We then parked directly over Marker 1M at a black smoker (Fig. 2.3.6) (x:5604, y:8196, d:2,164 m, a:6.1 m, h:064°) where the temperature of the fluid was 332.0°C. There was extensive diffuse venting in the area as well. At 2154, we collected fluid using the right half of the yellow major sampler, and at 2157 we did another flow meter measurement as described above. The orifice was again 3-4 cm in diameter and the flow rate was comparable to what we measured at Park Place.

We then drove SE across the valley again over the Knight vent where there were no black smokers seen but extensive diffuse venting and arrived at the Fairy Castle vent along the west wall of the horst. There was considerable diffuse venting below Fairy Castle on the west face of the horst and at the base of the Fairy Castle structure. At 2230, we stopped at one site at Fairy Castle where there were black smokers and extensive diffuse venting (Fig. 2.3.7) and measured fluid temperatures of 328.5°C at one black smoker. We then headed south across a large fissure and at 2242 arrived at the east wall of the horst at an extinct sulfide mound (x:5702, y:7983, d:2,135 m, h:110°). There were old tubeworm tubes in the area as well as a mooring line that was wrapped around a portion of the structure that constituted a navigation hazard. At 2245, we dropped weights and began our ascent (x:5711, y:7967, d:2,100 m). We arrived at the surface at 0000 UTC.

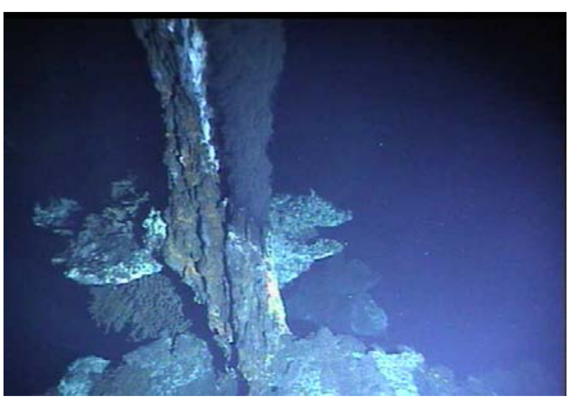


Figure 2.3.1. Bambi vent at the base of the Godzilla structure.

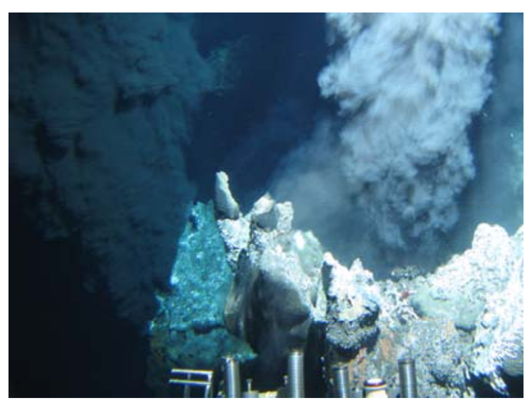


Figure 2.3.2. High temperature vent (right) on Godzilla where fluid samples were collected.

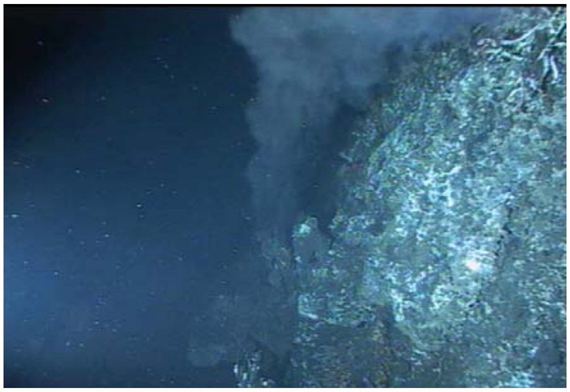


Figure 2.3.3. Park Place vent where high temperature fluids were collected.

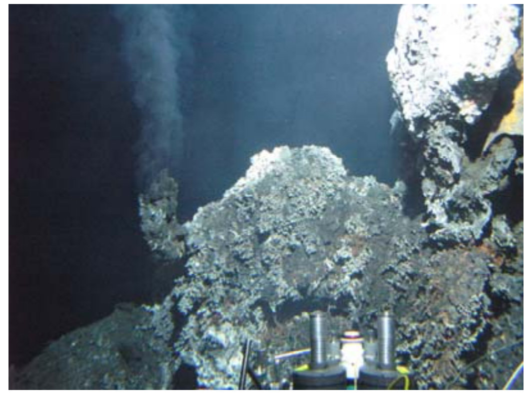


Figure 2.3.4. Baltic vent where high temperature fluids were collected.

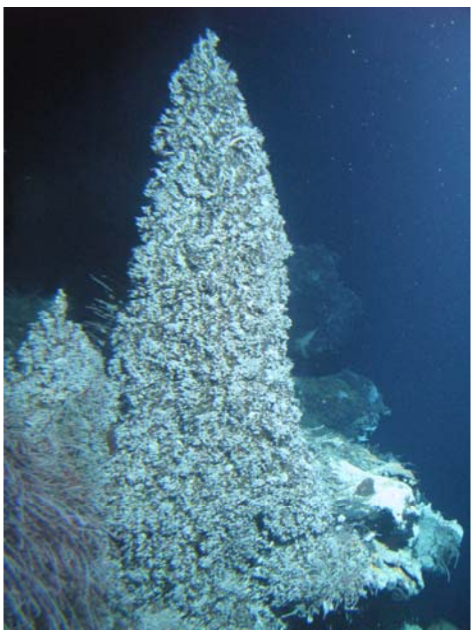


Figure 2.3.5. Diffuse fluid mound at Blue Moon covered in palm worms.

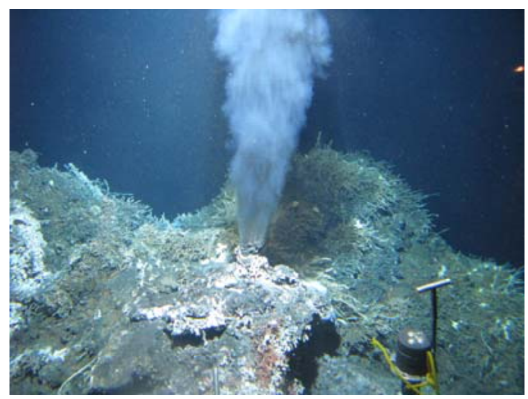


Figure 2.3.6. Ventnor vent where high temperature fluids were collected.

Figure 2.3.7. Fairy Castle vent surveyed for future sampling.

2.4 Dive 4517: Main Endeavour Field **June 16, 2009**

Pilot: Mark Spear

Port Observer: Rika Anderson

Starboard Observer: Candice St. Germain

Primary objectives: The objectives of this dive were to 1) collect extinct sulfide samples 2) move the barrel sampler into position on the diffuse venting shelf on SW side of Hulk, 3) collect HFS samples of high and low temperature vent fluid pairs from Hulk and Dudley, 4) collect gas tight fluid samples of high temperature vent fluid from Hulk, Dudley, and Crypto, 5) collect a paired sample of high and low flow *Ridgeia piscesae* tubeworms with matching HFS fluid samples from the Stunning site at Hulk, 6) and collect a basalt sample.

Sample summary: 9 HFS samples (3 filtered samples, 5 unfiltered samples, 1 sterivex filter), 1 gas tight, 1 sample of high flow *Ridgeia piscesae* tubeworms with matching HFS fluid sample, 2 extinct sulfide samples, and 1 basalt sample.

Dive Summary:

At the surface, after being in the water for 5 minutes, we turned on and tested the HFS sampler. Flow through the flush pump was confirmed. *Alvin* landed on the bottom at 1615 UTC east of Hulk (x:4934, y:6246, d:2075 m, h:309°). We headed to the location of the barrel sampler, which had been deployed the previous night. We located Hulk at 1642 and then continued searching for the barrel sampler. The barrel sampler was found at 1646 (x:5014, y:6273, d:2195 m). We released some weights from the elevator to make it more buoyant and then left it in place while we headed to Hulk (1653) for sulfide, fluid, and animal sampling. At 1704, we located a mound of extinct sulfide and took a small sample (x:5052, y:6249, d:2197 m) (Fig. 2.4.1). We headed off in search of the H marker, and drove around Hulk and Crypto before finding it at 1747 (x:5049, y:6242, d:2196 m, h:356°) (Fig. 2.4.2). At 1719, during our search for the H marker, we located an extinct sulfide spire and took a sample (x:5052, y:6247, d:2193 m) (Fig. 2.4.3). We located the diffuse flow shelf adjacent to the H marker and chose a low temperature fluid collection site after measuring temperature with the HFS sampler (x:5052, y:6243, d:2198 m, h:035°) (Fig. 2.4.4). There was a small spire (< 6” in height) venting clear, shimmering fluid surrounded by small tubeworms, palm worms, scale worms, and limpets. This spire was knocked over during the initial temperature probe. We collected 5 HFS samples (3 unfiltered, 1 filtered, 1 Sterivex) from 1817 to 1853 during which time the maximum temperature fluctuated between 17.1 and 41.2°C, and the average temperature fluctuated between 13.7 and 36.2°C.

We then headed to a high-temperature sampling site that had been located with video scans during the low temperature sampling time. This site was directly in front of the sub, within 10 m of the low-temperature sampling site (x:5053, y:6244, d:2197 m, h:022°) (Fig. 2.4.5). At this site, clear to black fluid was vigorously venting out of a small spire (~12” in height) with few animals surrounding the site. During the initial temperature probe the top of the spire was knocked off. The maximum temperature, as measured by the *Alvin* temperature probe, was 304.7°C. We collected HFS samples (1 filtered, 1 unfiltered) from 1904 to 1911 and at 1920 we collected another high temperature sample using the white gas tight sampler at the same site. We then headed up to the Stunning site, about 8 m up and to our left, to collect a high-flow tubeworm sample (x:5055, y:6248, d:2189 m, h:117°) (Fig. 2.4.6). We used the *Alvin* low-temperature probe to determine maximum temperature at both the plume and the base of the tubeworm bush. These were 9.6°C and 26.1°C, respectively. We then took 2 HFS samples at this site (1 filtered, 1 unfiltered) from 1948 to 1956. When we removed the fluid sampler a large clump of worms came with it. These were placed into the port side of the biobox and there was no need to grab more tubeworms with the claw. Between the initial temperature probe and the fluid sampling we had to reposition the sub and a small sample of tubeworms, palm worms, scale worms, and limpets fell into the starboard biobox from an overhang above the sampling site. These were retained, but there were no matching fluid temperature or chemistry samples. The overhang was sparsely covered in animals, not directly affected by shimmering fluid flow, and was slightly rust-colored (Fig. 2.4.7).

At 2000, we finished the high-flow tubeworm sample and went to pick-up the Barrel Sampler. At 2016, back at the barrel sampler location, we collected a basalt sample (x:5019, y:6273, d:2195 m, h:314°, T:3.8°C) (Fig. 2.4.8). From 2019 to 2035, we pumped water out of the *Alvin* ballast tanks to make the sub neutrally buoyant with the barrel sampler attached. We then headed back to Hulk and arrived at 2047, where we landed adjacent to our diffuse-flow sampling site and set the barrel sampler on the shelf, (Fig. 2.4.9). At 2110, we placed the barrel sampler intake funnel over a region of diffuse flow that was as close to the previous sampling site as possible. After switching on the pump, flow to the barrel sampler was confirmed at 0.25 gallons/minute, with a temperature reading of approximately 4°C. At 2116, the intake funnel was repositioned over a point source with slightly higher flow to attempt to sample higher temperature fluid (Fig. 2.4.10). At this point we were almost out of battery power and had to begin our ascent. We left the bottom at 2127.

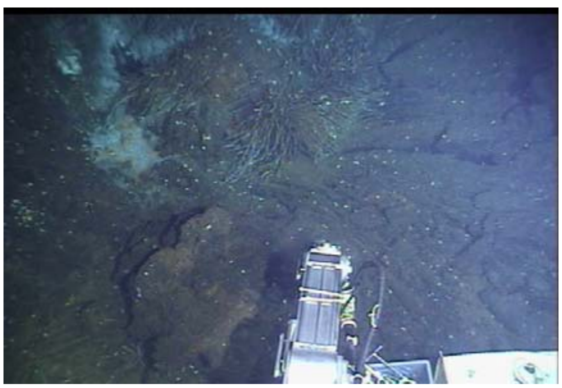


Figure 2.4.1. Collection of extinct sulphide sample #1 (to the left of the *Alvin* arm).

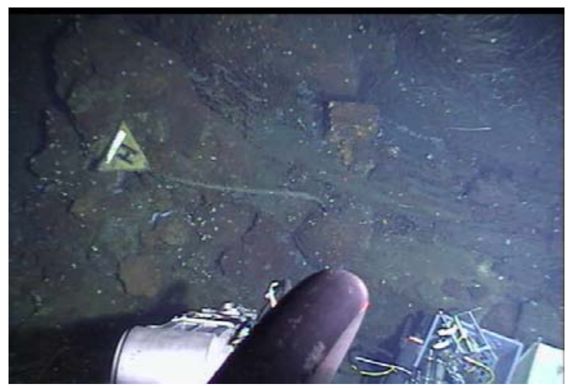


Figure 2.4.2. H marker at the base of Hulk vent.

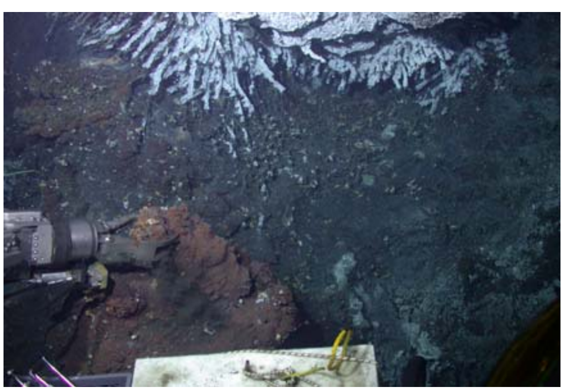


Figure 2.4.3. Collection of extinct sulphide sample #2.

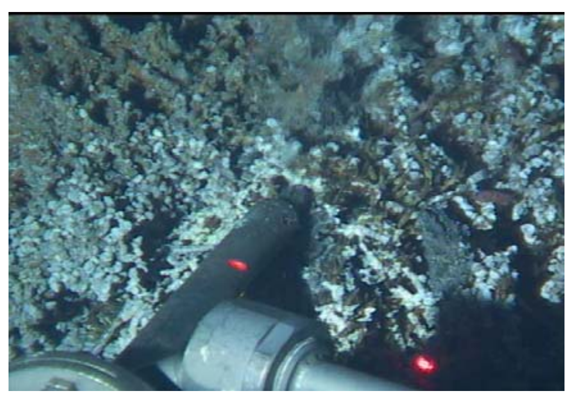


Figure 2.4.4. Collection of low temperature diffuse fluids from Hulk vent.

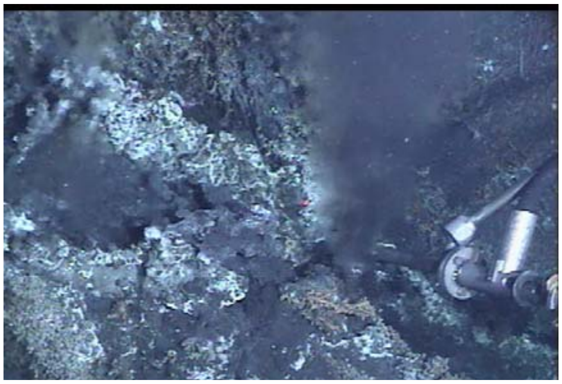


Figure 2.4.5. Collection of high temperature fluids from the Hulk structure.

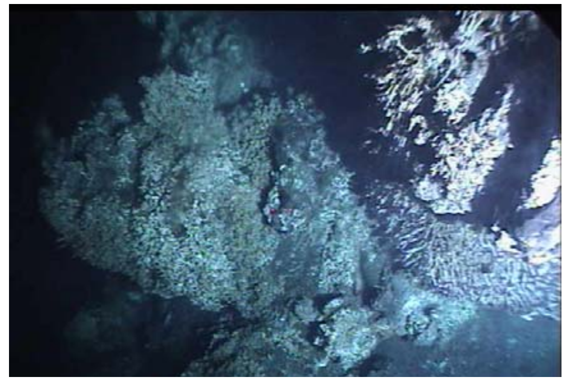


Figure 2.4.6. The high flow tubeworm sample site, the collected worms are seen in the lower right.

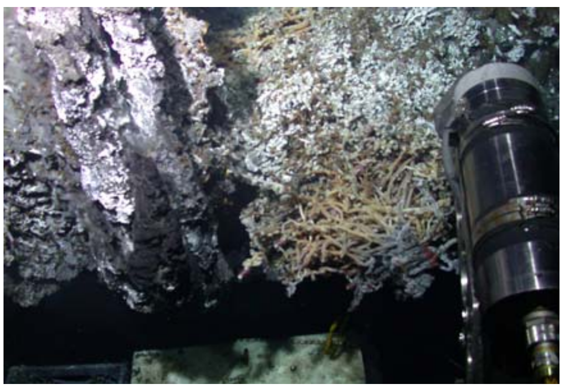


Figure 2.4.7. The overhang above the tubeworm sampling site.

Figure 2.4.8. Collection of the basalt sample.

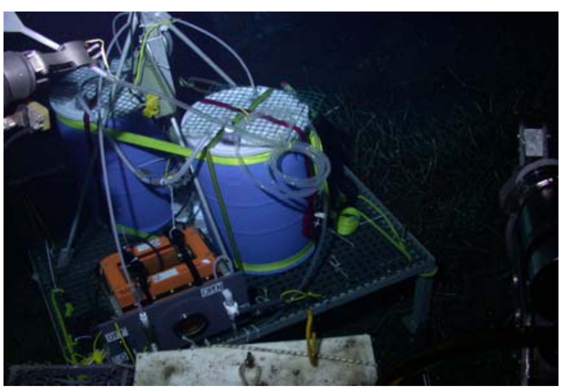


Figure 2.4.9. The final position of the barrel sampler following deployment.

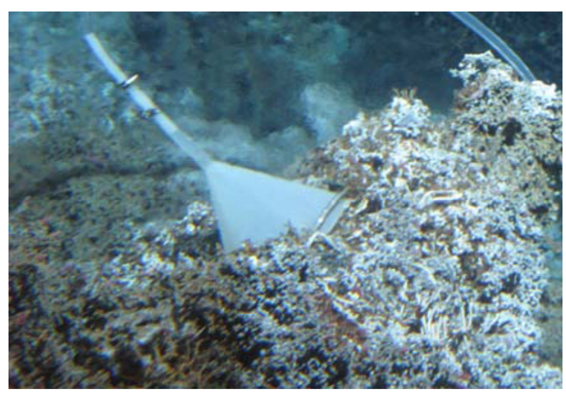


Figure 2.4.10. Final position of the barrel sampler intake funnel.

2.5 Dive 4518: Main Endeavour Field **June 17, 2009**

Pilot: Sean Kelley
Port Observer: Eric Olson
Starboard Observer: Leonid Germanovich

Primary objectives: The objectives of this dive were 1) release the barrel sampler at Hulk back to the surface, 2) deploy the resistivity-temperature sensor at Dante, 3) collect high temperature fluids and an active piece of sulfide from the site of the probe deployment, and 4) deploy the RAS mooring at Lobo.

Sample summary: 1 major pair, 2 gas tight samples, one piece of sulfide, flow meter measurement.

Dive Summary:

Note: no reliable in-hull LBL navigation was achieved during this dive. All XY's are Doppler fixes with several surface corrections (good LBL and USBL) applied during the dive. *Alvin* landed north of the Hulk structure in the Main Endeavour Field at 1612 UTC (x:5120, y:6427). The transit to Hulk took place on a heading of 200° and followed a fissure system. Eventually sulfides were encountered and *Alvin* transited along the west face of Hulk to the elevator site (x:5050, y:6218, d:2200 m). At the elevator (Fig. 2.5.1), time was spent adjusting switches and valves after adding the extra flotation brought from the surface. At 1719, the elevator was released after extra shaking to free the weights.

We then transited to Dante along a course of 190-200, again following fissures. The east face of Lobo was observed (including marker) and the north face of Dante was encountered. A survey of the perimeter was begun going along the east face. At 1743, a small chimney was closely observed (x:4986, y:6134, d:2186 m, h:121°). This site was abandoned after it was discovered that the *Alvin* high temperature probe and major pair ICL temperature probe were not operational. A second smoker site on the south face was occupied and further attempts at temperature measurement failed. We decided to find a large, fully venting orifice anywhere on the site to insure a good res-probe deployment. At 1827, a third smoker was found on the northern spire atop the Dante structure (x:4999, y:6136, d:2179 m, a:18 m, h:091°). This vent had a large sulfide candelabrum and was vigorously venting. At 1836, the candelabrum was sampled and placed in the biobox that resulted in a large venting orifice. At 1838, a flow measurement was easily made (Fig. 2.5.2) and then the yellow major pair and the red and blue gas-tight samples were collected at 1851 (x:4999, y:6135, d:2179 m, h:091°). A small amount of time was spent further excavating the hole to insert the res-probe. At 1903, the probe wand was inserted (Fig. 2.5.3) while monitoring temperature to assure maximum stable temperature. The data logger case was then moved off the basket to a location nearby (Fig. 2.5.4) (previously measured at 6-10°C with *Alvin* low temperature probe) and the data monitored again to assure that the probe was still fully inserted in high temperature flow. A position was obtained from the surface and in-hull navigation reset to that fix.

At 1925, *Alvin* then moved off to a nearby diffuse venting area (x:5005, y:6188, d:2194 m, h:213°) for another flow measurement and navigation was again reset to a surface fix. We then transited to the RAS sampler that had been dropped from the surface the previous night using the Homer tracking system. We arrived at the RAS at 2009 (x:4863, y:6116, d:2169 m, h:245°). The RAS ended up quite a bit further west and up the talus wall than anticipated but was eventually found. An *Alvin* drop weight was released and after ballast adjustment the RAS was moved down the wall, over the Grotto structure, and at 2023 into the proper Lobo location (x:4968, y:6163, d:2186 m, h:227°). The intake was moved several times with low temperature measurements of 12°C. An attempt was made to measure flow in the shimmering water at the intake but no movement of the meter wheel could be detected. There was not enough battery power for high temperature fluid sampling.

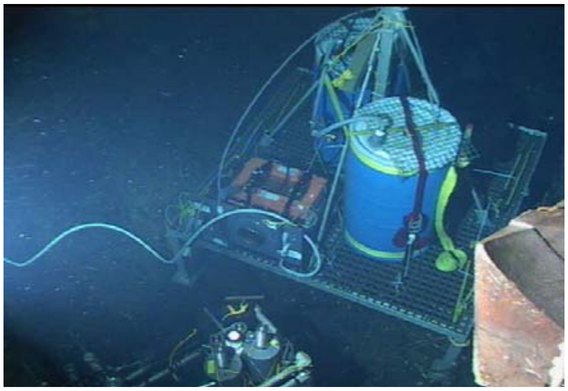


Figure 2.5.1. The barrel sampler at Hulk prior to its release to the surface.

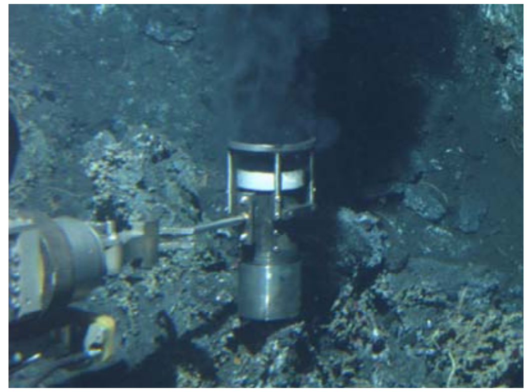


Figure 2.5.2. Flow meter measurement at Dante.

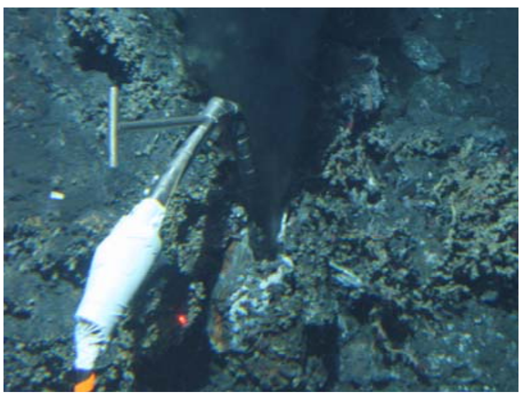


Figure 2.5.3. Insertion of the resistivity probe into a black smoker orifice at Dante vent.

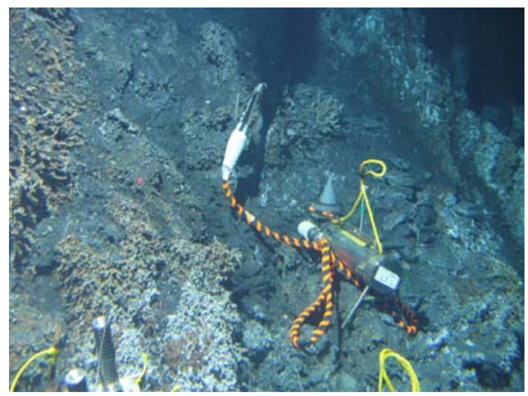


Figure 2.5.4. The data logger and probe deployed at Dante vent.

2.6 Dive 4519: ASHES, Axial Volcano **June 18, 2009**

Pilot: Bruce Strickrott
Port Observer: Kevin Roe
Starboard Observer: Dave Walter (PIT)

Primary objectives: The goals of the dive were to 1) collect fluids from low temperature vents at Gollum and Marshmallow; 2) collect high temperature fluids from Virgin Mound, Inferno, and Hell vents, and 3) collect a pair of tubeworm samples from a diffuse vent site.

Sample summary: 1 gas tight fluid sample, 10 HFS fluid samples (4 filtered, 4 unfiltered, 2 sterivex filters), 1 glass fiber filter, and 2 bundles of tube worms.

Dive Summary:

Alvin was launched at 1500 UTC and reached bottom at 1555 (x:4170, y:3645) and we drove to Gollum, passing over Virgin Mound in route. After surveying the area, we began sampling at Gollum at 1714 (Fig. 2.6.1). The target temperature from last year was about 22°C. At one point prior to sampling, we had the *Alvin* low temperature probe and the HFS snorkel in the same location. The *Alvin* probe registered 21°C, while we could get only a maximum of 17.5°C on the HFS temperature probe. As this was the best we could get, we began sampling. We got three unfiltered bags, one filtered bag, two sterivex filters, and one glass fiber filter. Total pumping time was about 90 minutes. We left Gollum at 1850. We originally were going to go to Marshmallow, but headed in the direction of Inferno. We settled down at 1856 (x:4122, y:3731) thinking that we were at Inferno. We got a maximum temperature of 270°C on the *Alvin* high temperature probe but were not able to get above 60°C on the HFS. There was no good focused flow. In fact, we were not at Inferno but rather at Mushroom (Fig. 2.6.2). We did not sample. We then went to Inferno (Fig. 2.6.3) (x:4112, y:3736) very close to our prior location. We took filtered and unfiltered pistons and the white gas tight at Inferno, with a steady temperature of 295°C. We then went in search of nearby tube worms for Candice's experiment. We collected fat tube worms (Fig. 2.6.4) and a filtered bag (#18) in 10.8°C flow (x:4118, y:3744, h:316°). We then collected skinny tube worms (Fig. 2.6.5) in a no visible flow area (x:4113, y:3744, h:253°) and a filtered water sample (#5) with a maximum temperature of 3.8°C, above the ambient temperature of 2.4°C. We were then out of power after 5 hours of bottom time and dropped weights.

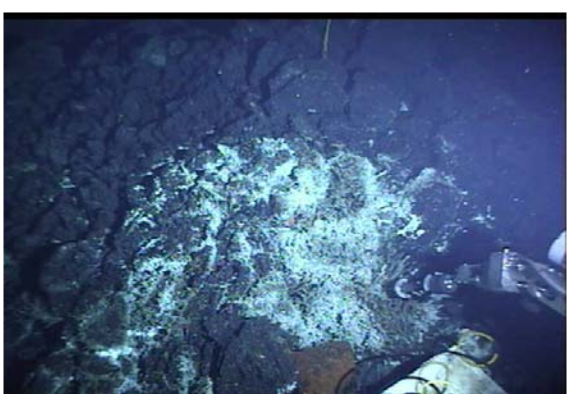


Figure 2.6.1. Sampling low temperature diffuse fluids at Gollum.

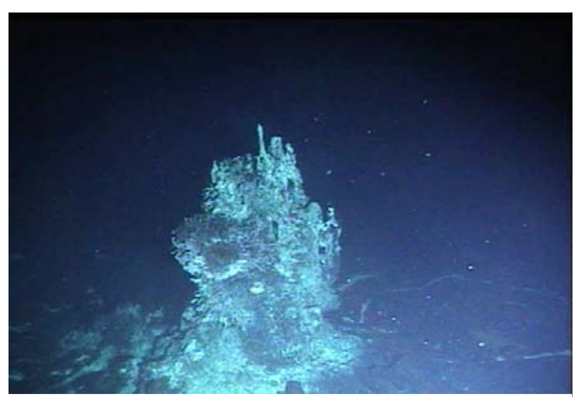


Figure 2.6.2. The Mushroom vent site.

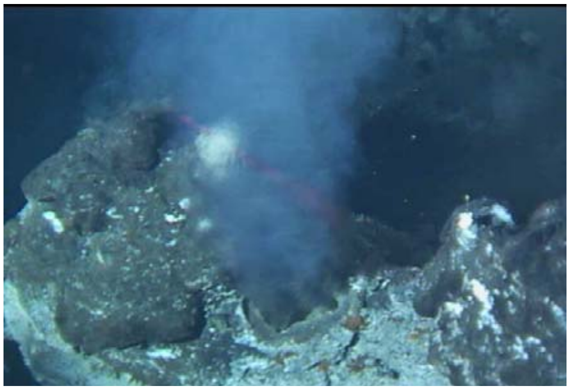


Figure 2.6.3. The high temperature fluids at Inferno where samples were collected.

Figure 2.6.4. The fat and short tubeworms collected near Inferno.

Figure 2.6.5. The long and skinny tubeworms collected at a site near the other tubeworm collection.

2.7 Dive 4520: Marker 113, Axial Volcano **June 19, 2009**

Pilot: Mark Spear
Port Observer: Dave Butterfield
Starboard Observer: Kerry McPhail

Primary objectives: The objectives were to 1) conduct intensive fluid sampling at and around Marker 113 to determine spatial variability, 2) sample biota for marine natural products screening and the tubeworm morphotype study, 3) conduct a short down-looking video survey of Marker 113 area, and 4) collect high and low temperature fluid samples from the International District.

Sample summary: 13 HFS fluid samples (4 filtered, 5 unfiltered, 4 sterivex filters) and 2 suction samples.

Dive Summary:

The sub began its descent at 1705 UTC after a two hour weather delay and we landed in the Axial valley just east of marker 113/62 at 1750 (x:6313, y:2562, d:1,519 m). We drove west about 240 m and reached marker 113/62 at 1823 on a lava pillar at the edge of a collapsed area (Fig. 2.7.1) (x:6070, y:2552, d:1,521 m, h:033°). After several minutes of temperature probing, the HFS sampler was positioned towards the edge of the pillar top beneath a cluster of tube worms (Fig. 2.7.2) and diffuse fluid sampling commenced at 1835 (x:6070, y:2551, d:1,522 m, h:035°). Over a one hour period at this site, we collected a filtered piston, two unfiltered bags, two sterivex, and one unfiltered piston at average temperatures ranging from 25 to 34°C. At 1944, we moved approximately 40 m south to another area of diffuse venting (10°C fluids, Fig. 2.7.3) where we began sampling at 1955. A peach-colored (and some white) microbial mat was collected from a bush of *Ridgeia* tubeworms with the red suction sampler, and fluid samples including an unfiltered bag, a filtered bag, and a sterivex were taken in immediate proximity (x:6073, y:2510, d:1,522 m, h:027°). We left this second site at 2034 and arrived at a third site 57 m south of marker 113/62 (x:6078, y:2493, d:1,521 m, h:014°) to begin HFS sampling at 2053 (Fig. 2.7.4): a filtered bag, an unfiltered bag, and a sterivex were collected. After moving a few meters west (x:6065, y:2490, d:1,521 m, h:022°), at 2130 we also collected some white bacterial mat directly from basalt substrate with the white suction sampler (at approximately 12°C). Up to this point, no fat tubeworms in sufficient abundance for collection were observed.

Therefore, at 2138, we headed northeast to the International District in order to collect high-T/low-T fluid sample pairs and possibly tube worms from El Guapo. In transit (h:055°, alt: 5 m) we observed lobate lavas collapsed in places with numerous flow channels and frequent pockets of tan-colored sediments, but no venting was seen.

After traversing approximately 640 m, we arrived at an extinct chimney at 2205 (x:6710, y:2946, d:1,514 m, h:034°) and a large active chimney at 2207 (Fig. 2.7.5) (x:6733, y:2981, d:1,515 m, h:348°). We then began searching for El Guapo. Escargot was observed from the port side at 2215 (x:6725, y:2994, d:1,512 m, h:343°) and we reached Hermosa at 2222 (x:6671, y:2969, d:1,510 m, h:228°). The next flat/square-topped pillar reached at 2227 was later tentatively identified as "9 Meter" (x:6683, y:2960, d:1,509 m, h:079°). After visiting this pillar, which had some blue protozoan mat growing on it, we realized that we had missed El Guapo and so we executed a loop in the hope of finding El Guapo on our subsequent approach to this area of International District. However, the next and last pillar that we sighted (at 2255) was on a heading of 022° (x:6703, y:3002, d:1,507 m). At this point, battery power was low and we began our ascent at 2300. This area was revisited on dive #4522 and El Guapo was sampled successfully.

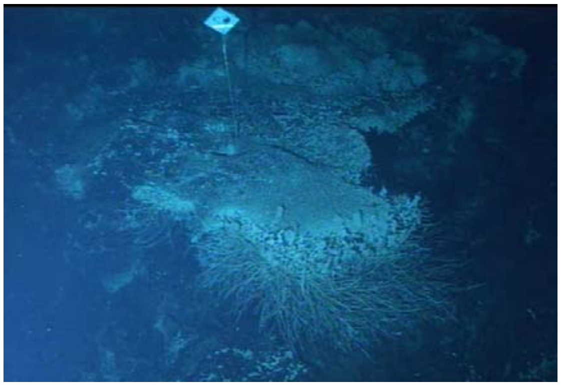


Figure 2.7.1. Marker 113/62 on flat topped pillar.

Figure 2.7.2. HFS sampling at the edge of the Marker 113/62 plateau.

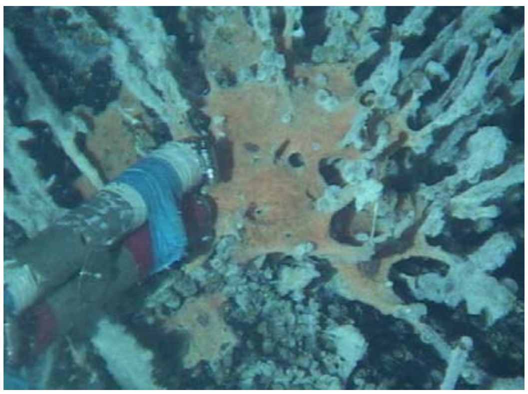


Figure 2.7.3. Peach microbial mat sampled at the second Marker 113/62 site.

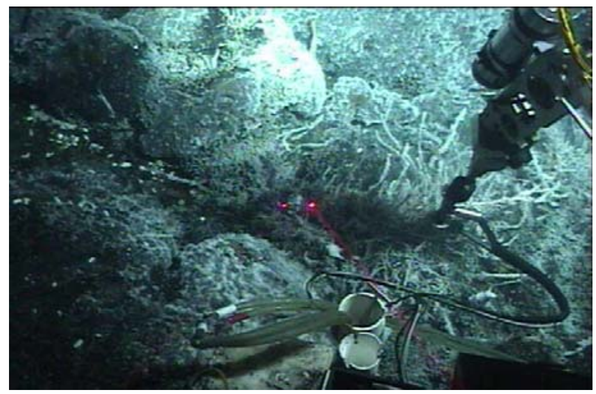


Figure 2.7.4. HFS fluid sampling at third Marker 113/62 site.

Figure 2.7.5. Sulfide pillar observed at 2207 UTC.

2.8 Dive 4521: Marker 33 and Cloud vent, Axial Volcano **June 20, 2009**

Pilot: Sean Kelley
Port Observer: Annie Bourbonnais
Starboard Observer: Sanjoy Som

Primary objectives: The objectives were to 1) release the RAS23 mooring at marker 33 and deploy a new RAS at the same location, 2) collect fluid and sterivex filter samples from the hole in the cover of the RAS and white microbial mats beneath the cover, 3) take flow measurement at Marker 33 using the Germanovich flow meter, 4) find and collect high-flow ("fat") and low-flow ("long and skinny") pair of *Ridgeia piscesa* worms and fluid samples from the same location, 5) transit to Cloud and collect fluid and sterivex samples and a suction sample (microbial mats) and 6) explore the large mound discovered in the MBARI AUV high-resolution bathymetry maps north of the International District vents and collect a sulfide sample at the base of the mound if the mound is indeed a sulfide.

Sample summary: 4 gas-tight fluid samples, 16 HFS fluid samples (6 filtered, 7 unfiltered, 3 sterivex filters), 1 basalt, and 2 tubeworm samples.

Dive Summary:

We reached the bottom at 1559 UTC at a depth of 1,520 m after a 55 min descent. We landed on ropy pahoehoe basalt, heading 069°. The RAS mooring was detectable by a homing beacon at a distance of 70 m from our position. We reached Marker 33/55 (x:6538 y:3681) at 1618 and diffuse flow was immediately visible. Using the *Alvin* High-T probe, we measured a fluid temperature of 20°C and deployed the Germanovich flow meter. We took an unfiltered piston (#3), two sterivex (#10 and #11), 3 unfiltered bags (#19, 21, and 22), a GFF filter (#20), a gas tight (black), and a suction sample (white mat under the cover of the RAS). The fluid temperature (~34°C) remained stable during sampling. At 1829, we started moving the old RAS away from Marker 33/55 and release it at 1831. The new RAS was located with the new homer 90.6 m away. We picked it up at 1902 and returned to Marker 33/55 bearing 126°. The new RAS was fully deployed at 1946 (Fig. 2.8.1). At 1951, we started heading for Cloud bearing 023°.

On our way, 16 m NE of Marker 33 (x:6550, y:3691, d:1521 m, h:060°), we found a new location (x:6550 y:3691) containing both high-flow ("fat") and low-flow ("long and skinny") *Ridgeia piscesa* tubeworms (Fig. 2.8.2). Both types were about two feet apart. We took a filtered piston (#7) at the base of the fat tubeworms and a piston (#6) in the plume above the high-flow tubeworms, with average temperatures of 9.7°C and 4.9°C, respectively. We also took a filtered piston (#5) at the base of the low-flow tubeworms (4.4°C), where no apparent plume-flow was seen. At 2032, we transited to Cloud and located the pit vent (Fig. 2.8.3) with the smiley face marker deployed last year (x:6585, y:3691, d:1522 m, h:324°). The average temperature of the sampled fluid (about 5.4 to 5.9°C for most samples) was slightly lower than last year (6.9°C). We took two unfiltered bags (#23 and #24), a filtered piston (#1), and a sterivex (#12). The average temperature of the fluid in the filtered piston #1 was lower than for the other samples (2.7°C) but we moved the intake and read a temperature of 5.9°C before taking sterivex #12. We then took a suction sample (white microbial mat) and the green gas tight.

At 2135, following the sampling of a basaltic sample, we headed to the large mound north of the International District vents (x:6634, y:3474, d:1515 m, h:164°). We mostly saw basalt pillars, collapse structures, and pillows. There was no indication of hydrothermal venting. In some areas, the basalt was covered with a yellow-brown drape (Fig. 2.8.4). It was unclear whether this represented a sedimentary drape, or a very ancient sulfide deposit. We did not find any sulfides to sample. At 2212, still at the top of the mound (x:6788, y:3076, d:1500 m, h:124°), we released the weight and ascended to the surface. On the way up, we flushed the HFS and took 2 background water samples (unfiltered piston #4 and filtered bag #16) and a sterivex (#14).

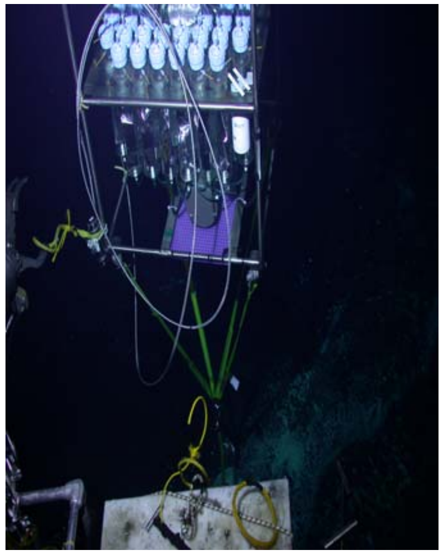


Figure 2.8.1. Deployment of the new RAS sampler at Marker 33.

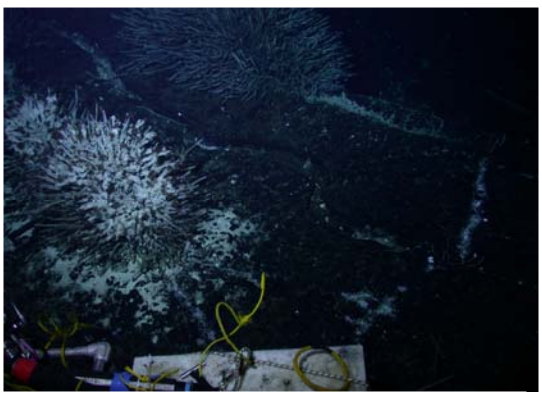


Figure 2.8.2. Sampling of high- and low-flow tubeworms near Marker 33.

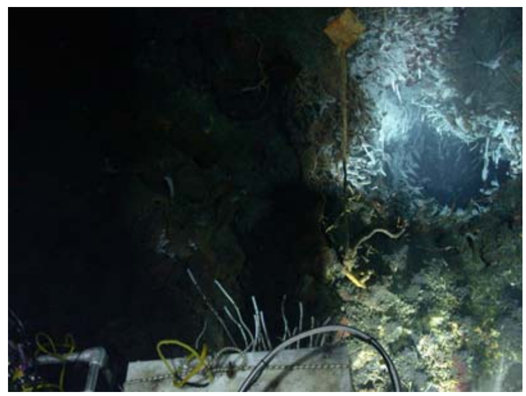


Figure 2.8.3. Venting and Cloud vent.

Figure 2.8.4. Large mound north of the International District vents were mostly pillow basalt (left), along with pillars and collapsed structures (right), discrete yellow-brown drape occasionally covered with clear brown sediments.

2.9 Dive 4522: International District, Axial Volcano **June 21, 2009**

Pilot: Bruce Strickrott
Port Observer: Dave Butterfield
Starboard Observer: Vyll Cameron

Primary objectives: 1) Fluid sampling of high- and low-temperature fluids in the International District, 2) collect a pair of co-located tubeworm samples, and 3) measurement of fluid flow with Germanovich flow meter.

Sample Summary: 11 HFS fluid samples (4 filtered, 5 unfiltered, 2 sterivex); 6 gas-tight fluid samples; 2 sulfide pieces; slurp samples (limpets, blue protists); tubeworms (*Ridgeia piscesae*)

Dive Summary:

The dive commenced at 15:00 UTC. At 1552, we reached the bottom (x:6828, y:2900, d:1,437 m). After travelling north, we encountered a ridge of lobate basalt due south of what was thought was Escargot vent. This turned out to be our first vent, Diva, which we reached at 1602 (x:6796, y:2925, d:1,518 m, h:089°). Diva is a small anhydrite vent and initial temperature measurements of the venting diffuse fluids were 215°C. Life around the vent was sparse and consisted of only a few *Ridgeia piscesae* tubeworms, blue protists, and white filamentous mats lining the cracks between basalt lobes, at and around the base of the vent. Low temperature bag (~18°C) and high temperature piston (~170°C) filtered and unfiltered fluid samples were collected as well as a sterivex filter sample. Additionally, red and yellow gas tights, a small piece of active sulfide and a slurp sample consisting of limpets and blue protists were also collected. Marker 151 was placed at the site before sampling began at 1614 (x:6798, y:2926, d:1,520 m, h:123°).

At 1738, we left Diva with a heading of 145° towards Escargot for a reference point. Escargot was reached at 1751 (x:6783, y:2940, d:1,515 m) but samples were not taken. We arrived at Hermosa at 1756 (x:6776, y:2944, d:1,517 m, h:232°). Some diffuse flow was observed at the vent base but not at the top and most of the structure was covered by worms and blue mats. A sizeable tubeworm sample was taken at x:6775, y:2943, d:1,518 m. Temperature measurements at the tips and base of the tubeworm clump were 13.8°C and 37°C, respectively. Initially, we did have some problems with the fluid sampler – it was thought that the nozzle was clogged but the primary problem turned out to be a kink in the hose. Bruce eventually managed to 'unkink' it so we could get on with fluid sampling. Two unfiltered and one filtered low temperature fluid samples and a sterivex were collected (x:6775, y:2943, d:1,518 m, h:223°) within and close to the tubeworm bush that was previously sampled. We left Hermosa at 1935 en route to El Guapo.

At 1940, we reached El Guapo (x:6755, y:2944, d:1,510 m, h:061°). This was the largest and hottest vent we visited at Axial, displaying significant venting through the sides and base of the main chimney structure. Phase separation was seen at some of the secondary vents branching off the main chimney. One of the first samples collected was a very large piece of active sulfide (d:1,506 m, h:048°) which was taken from a vent structure emitting 330°C fluids. In addition, one filtered (290.5°C) and unfiltered piston (297°C) samples, two gas tight fluid samples in the 330°C fluids and another two gas tights higher up the structure at a boiling orifice (350°C) were collected. Marker 152 was placed at the base of the vent (x:6757, y:2951, d:1,514 m, h:268°). Our dive was completed at 2023 when Alvin's batteries ran out of power.

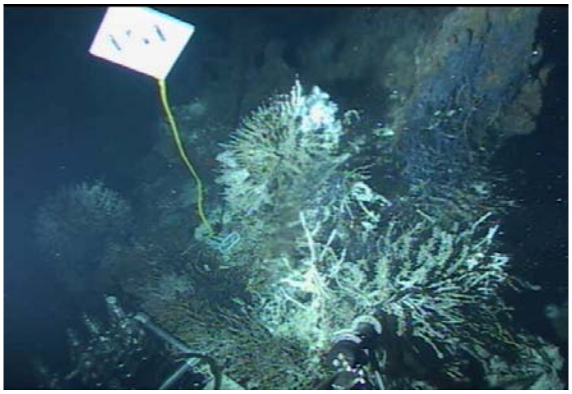


Figure 2.9.1. Placement of Marker 151 at Diva vent.

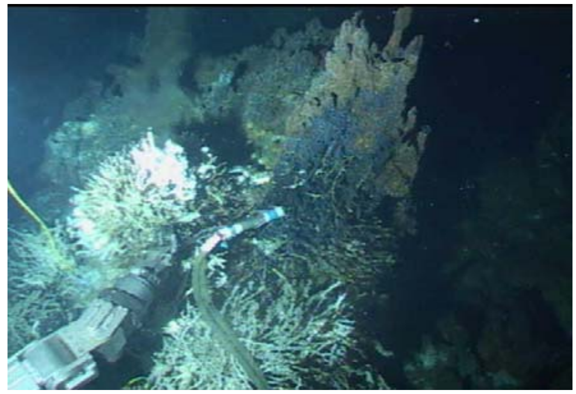


Figure 2.9.2. Sampling of blue protest mat at Diva vent.

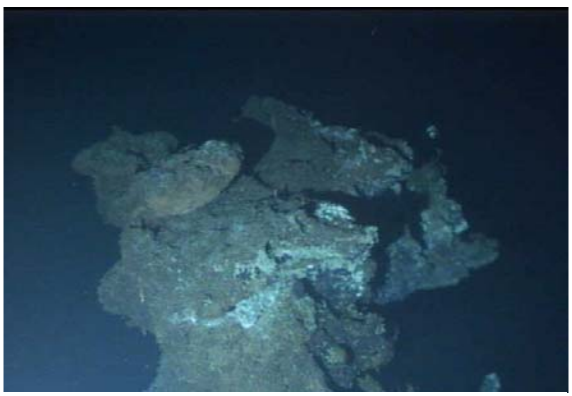


Figure 2.9.3. Escargo sulfide structure.

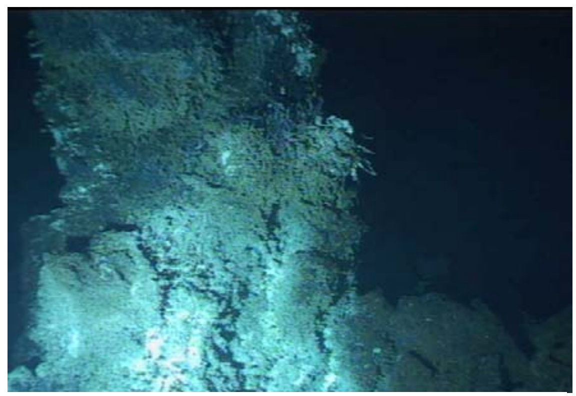


Figure 2.9.4. Hermosa sulfide structure with venting.

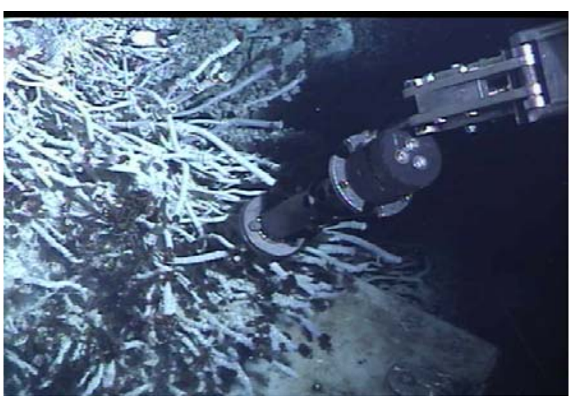


Figure 2.9.5. Low temperature fluid sampling at Hermosa where tubeworms were collected.

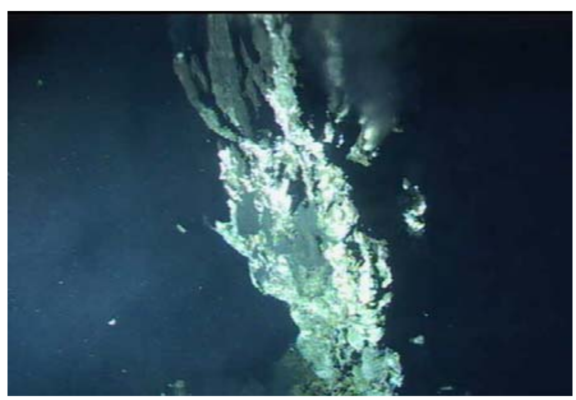


Figure 2.9.6. El Guapo vent with phase separation evident at the top right. Marker 152 was placed at the site.

2.10 Dive 4523: Main Endeavour Field **June 22, 2009**

Pilot: Mark Spear
Port Observer: Dave Butterfield
Starboard Observer: Hakon Dahle

Primary objectives: The objectives were to 1) collect high and low temperature fluid samples from the northern and southern region of the Main Endeavour Field (Grotto, Lobo, Bastille/Easter Island, S&M, Salut) and 2) move the RAS from Lobo to Easter Island for the second portion of its short-term deployment.

Sample summary: 3 gas-tight fluid samples, 21 HFS fluid samples (10 filtered, 6 unfiltered, 4 sterivex filters, 1 large volume bag), 2 sulfide samples (1 active, 1 extinct).

Dive Summary:

We arrived on the seafloor at 1612 UTC in the open area south of Grotto. We drove NW and slightly up the talus slope, turned north for a short distance, and found sulfides and marker G at Grotto. We then moved a few meters to the east along the southern edge of Grotto and found a smoker and diffuse flow area at 2,187 m depth. We set up and sampled diffuse and hot fluid 20 cm apart. The maximum temperature with *Alvin* high-T probe was 340.6°C at the Grotto smoker, and 18 to 21.9°C in the diffuse flow. Here we took the white gas-tight, filtered piston #1, unfiltered piston #2. In the diffuse flow we took unfiltered bag #24, filtered bag #19, and a sterivex filter for DNA. We drove around the east end of the Grotto structure that we sampled, but did not immediately see the RAS instrument on Lobo. Using the Sonardyne beacon 17 on the RAS mooring line, we found the mooring and followed the line down to the RAS (x:4935, y:6170, d:2187 m). From the instrument, we moved about two meters (x:4934, y:6170) toward the center of the structure to sample a smoker vent. The maximum *Alvin* high-T measurement was 296.5°C. This was a difficult vent to sample (small orifice and not easy to reach) and we took only one HFS sample plus the black gas-tight. We moved back to the RAS and took one unfiltered piston and one Sterivex filter with temperatures of 8.8°C.

We pumped out over 100 pounds of water to allow us to pick up and move the RAS from Lobo to Easter Island, by driving a short distance SW and then due south. There was a significant smoke cloud over Grotto and Lobo. We did not see the Easter Island marker, but found a small mound of sulfide growing on basalt, which looked suitable for the RAS deployment. Our heading while deploying the RAS was 306°, with a steep sulfide to our port. We took two unfiltered bags (8.4°C and 9.1°C) and a Sterivex filter (9.3°C) at this site. We then installed the RAS intake with 3 MTR temperature sensors into the vent. Temperature measured with the low-T probe beneath the downward facing intake was up to 12°C, so it appears that the installation was good. The vent is within 2 m of the base of Bastille on the north side (x:4872, y:6012, d:2193 M). From the RAS site, we drove south around the east end of Bastille, past Sully, and near Puffer to the markers triangle B and carved P on the SW base of Bastille. The reason the P marker is in this spot may be that when looking straight at it, the submarine would be pointed at Puffer. Saw the Puffer vent that was sampled in time series in 1995, which appeared to be completely inactive. The maximum temperature by *Alvin* high-T at the Bastille smoker was 326.8°C. At this point, we were completely out of power and had to stop without sampling at 2200.

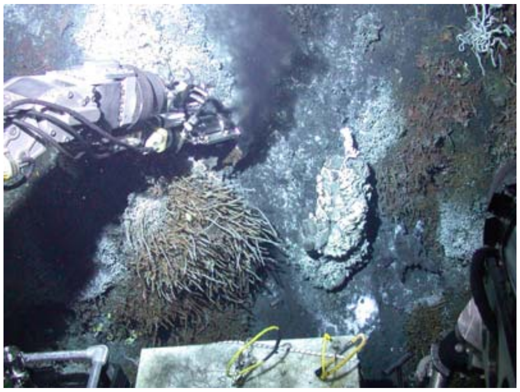


Figure 2.10.1. Site of high and low temperature fluid sampling at Grotto vent.

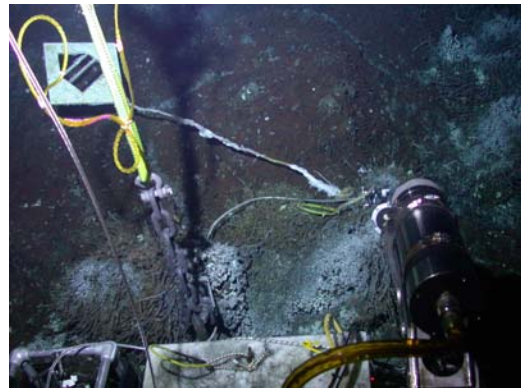


Figure 2.10.2. Deployment of the RAS sampler at a diffuse site at Lobo vent.

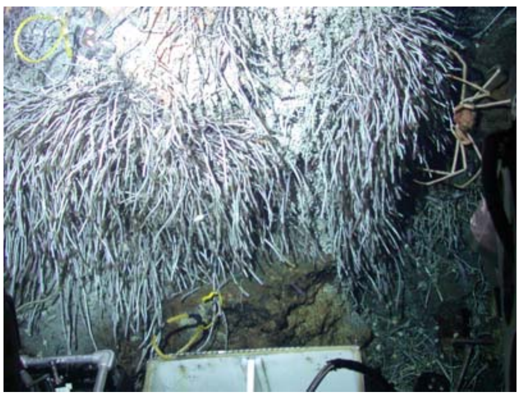


Figure 2.10.3. The RAS intake nozzle in place near Bastille vent.

2.11 Dive 4524: Mothra Field **June 23, 2009**

Pilot: Sean Kelley
Port Observer: Jim Holden
Starboard Observer: Jeff McDonald (PIT)

Primary objectives: The objectives of this dive were to 1) collect high and low temperature fluid pairs at 2-3 sites 2) collect a large piece of sulfide for geochemical and microbiological analyses, and 3) collect tubeworms.

Sample summary: 6 HFS fluid samples (2 filtered bag, 3 unfiltered bags, and 1 sterivex).

Dive Summary:

Alvin was launched at 1500 UTC and reached the bottom at 1620 east of the Faulty Towers complex (x:4247, y:3298, d:2272 m). The sub approached the Faulty Towers complex from the south and at 1701 was positioned at the Roane vent (x:3311, y:2271, d:2271 m, alt:11.3 m, h:023°). The goal was to collect fluids from Roane and wiggle the plug in the side of Roane (Fig. 2.11.1) to ensure that the hole remained open. The temperature of the fluid emitted from Roane was ~2°C, or just barely above the temperature of background seawater so no fluids were collected. The pilot was also unable to reach the plug so it was not moved. We then attempted to collect co-localized high and low temperature fluids at Faulty Towers and at 1730 positioned ourselves near diffuse venting at Phang vent (Fig. 2.11.2) (x:4168, y:3311, d:2273 m, alt.:11.1 m, h:003°). At one site, the temperature was 180°C, which was too hot for our low temperature sampling needs. Another location was 23°C but we were unable to hold that position due to a strong sideways current. At 1751, we repositioned ourselves just below the Phang stump at another diffuse vent site (x:4169, y:3310, d:2276, alt.:9.7 m, h:013°) and measured fluid temperatures of 27°C using the high-T probe. Between 1810 and 1858, we used the HFS to collect 2 filtered samples, 3 unfiltered samples, and a sterivex filter sample with temperatures ranging between 21 and 26°C (Fig. 2.11.3). As we finished sampling at Phang, we were alerted by the surface that surface conditions were deteriorating and that we needed to return to the surface immediately. We dropped weights at 1908 after driving a short distance away from Faulty Towers (x:4239, y:3297, d:2278 m).

Figure 2.11.1. Profile of the Roane vent structure with HOBO T probe in the side.

Figure 2.11.2. Profile of the Phang vent where fluid samples were collected.

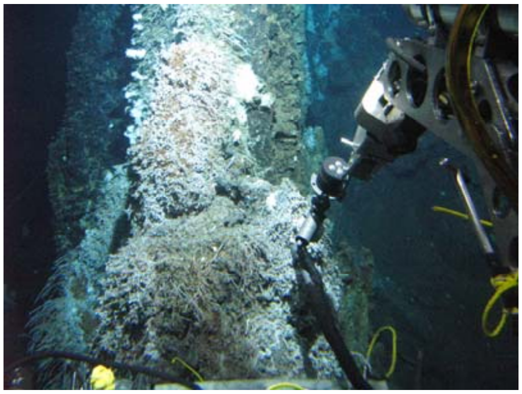


Figure 2.11.3. Low temperature fluid sampling at Phang vent.

Figure 2.11.4. Macrofauna observed near the site of fluid sampling at Phang vent.

2.12 Dive 4525: Main Endeavour Field **June 25, 2009**

Pilot: Mark Spear
Port Observer: John Jamieson
Starboard Observer: Keith Grochow

Primary objectives: The objectives were to 1) release the RAS fluid sampler at diffuse venting site near Easter Island/Bastille, 2) retrieve the resistance probe at Dante, 3) collect high-temperature fluid samples from Bastille and Dante 4) evaluate the functionality of integrated COVE software with *Alvin* navigation.

Sample summary: 4 gas-tight fluid samples, 3 HFS fluid samples (2 filtered, 1 unfiltered), and 1 extinct sulfide.

Dive Summary:

Alvin was launched at 2005 UTC after a 7 h delay due to rough seas and arrived at the bottom at 2314, almost directly above the N-marker atop Needle. The floats for the RAS fluid sampler that was to be released from the Easter Island/Bastille area was observed out of the port window as we approached the bottom, making it easy to locate the RAS sampler once reaching the bottom. The RAS was released at 2330 from the top of the NE corner of Bastille, near Needle (x:4875, y:5996, z:2194 m). We then proceeded to the south face of Bastille where we completed high-temperature sampling of hydrothermal fluid (x:4888, y:6010, z:2194 m, h:106°, alt:0.9 m) from a site that was previously sampled for low-temperature diffuse flow. The *Alvin* high-T temperature probe had a grounding problem and was therefore inoperable for the entire dive. Temperature measurements were made using the temperature sensor on the HFS. Two piston samples were taken with the HFS: a filtered piston sample at 0011 (317.5°C), an unfiltered piston at 0015 (316.9°C). Two gas-tight samples were also collected at the same site (yellow-black gas-tight sampler at 0023 and orange gas-tight sampler at 0026).

At 0028, we departed and headed north to Dante. Navigating to Dante was difficult due to the absence of LBL navigation. At 0040, we arrived at a sulfide structure that was originally thought to be Dante. However, the shape, size and depth of the structure led us to conclude that we had drifted too far east and were at Dudley. We then headed NW and found another steep-sided sulfide structure at 0050. A barely-floating diamond shaped marker observed at the top of this structure was likely the RAS marker at Lobo, which indicated that we had past Dante as we drove NW from Dudley. After turning around, we quickly located Dante at 0054 and found the resistance probe two minutes later (0056) atop the structure (x:4965, y:6168, z:2180 m, h:069°, alt:1.1 m). The probe was carefully removed from the black smoker orifice and held in place so that the tip could be examined with the cameras. The sulfide structure being precipitated by the venting fluid had grown around the end of the probe. When the probe was removed, a large piece of sulfide remained attached to the probe, and was broken off when the probe was placed in the basket. A temperature of 338.4°C for the venting fluid was measured using the temperature probe on the HFS. Two gas-tight samples were taken from the open venting orifice (green gas-tight sampler at 0112 and unmarked gas-tight sampler at 0116).

At 0117, we were informed from the surface that we would have to drop weights to surface in 10 min., due to daylight constraints for recovery. We therefore did not have any time to proceed to any other sulfide structures for fluid sampling. Instead, we took a flow meter measurement at the previously-sampled vent on Dante using the Germanovich flow-meter. The flow meter was positioned so that the minimum amount of high-T fluid spilled outside of the flow meter. The rotation of the flow meter was recorded for 5 min, starting at 0119. We then proceed to the base of Dante and collected a sulfide that was broken off from the base (x:4991, y:6180, z:2193 m, h:013°, alt.:3.0 m). The sample was large (~50 cm x 40 cm x 25 cm) and was placed on the plywood cover for the HFS. At 0135, weights were dropped and we started our ascent to the surface. At 0136, a background seawater sample at 1.8°C was collected with the HFS in a filtered bag (x:4988, y:6175, z:2100 m). At 0146, due to a slow ascent rate, the port manipulator arm was used to break off a piece of the extinct sulfide and the rest of the sample was dropped off of the basket. *Alvin* surfaced at 0205. Total bottom time was 2 hours 20 minutes.

The COVE software was used throughout the dive to track position of *Alvin* using the UDP broadcast of the Doppler based positioning system on board. COVE received the position information and then projected the position of *Alvin* against 3 m resolution bathymetry (provided by the University of Washington) in an interactive 3D environment. As well as the current position, the dive track was presented. The software was useful in several ways. Before the dive, the site could be evaluated from many angles and scales with the pilot to determine the best routes to take. On the way to the bottom, observers new to this site could gain context quickly (Fig. 2.12.6). Once on the bottom, COVE was very helpful in providing navigational aid to the pilot by showing the position and bearing of the sub in the context of the bathymetry. By comparing the screen to observed structures outside, we were able to quickly determine necessary corrections. For example, after releasing the RAS and going to Bastille, we determined we needed to make a 180° turn to find the marker (Fig. 2.12.7). The final position was within 3 meters of the one projected by COVE. Finally on completion of the dive, the complete course of the dive was immediately available for help in discussion with other scientists (Fig. 2.12.8). The recommendation of the *Alvin* team and the science team was to pursue funding to continue to enhance COVE and make it available for future cruises.

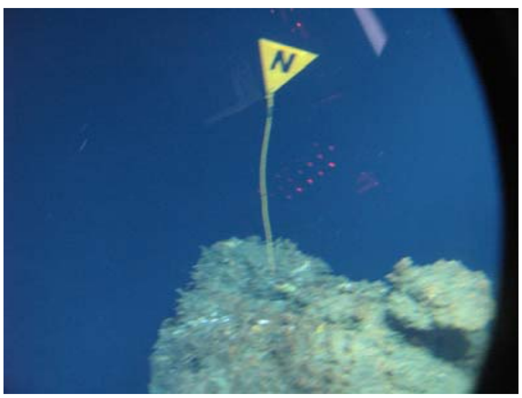


Figure 2.12.1. N marker atop Needle vent near the RAS site.

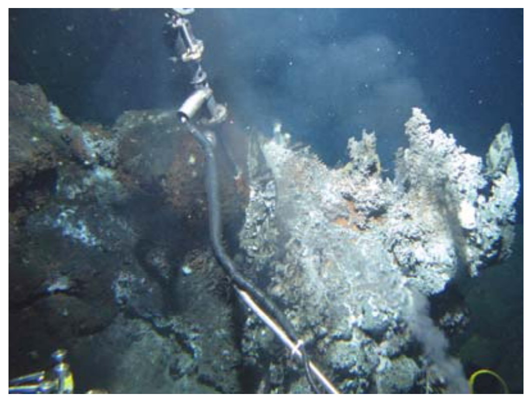


Figure 2.12.2. High temperature fluid sampling at Bastille vent.

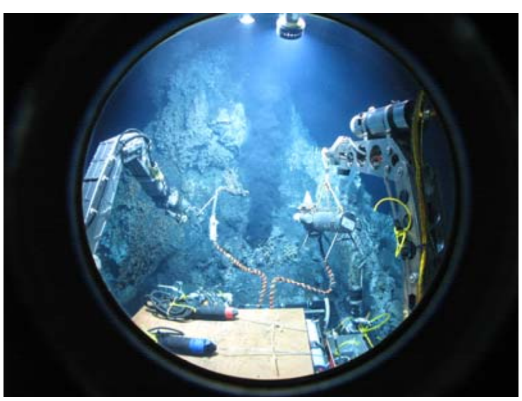


Figure 2.12.3. Removal of the resistivity probe from the vent at Dante.

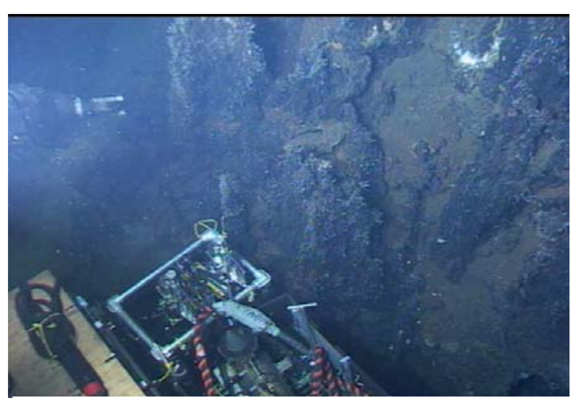


Figure 2.12.4. Collection of the inactive sulfide at the base of Dante vent.

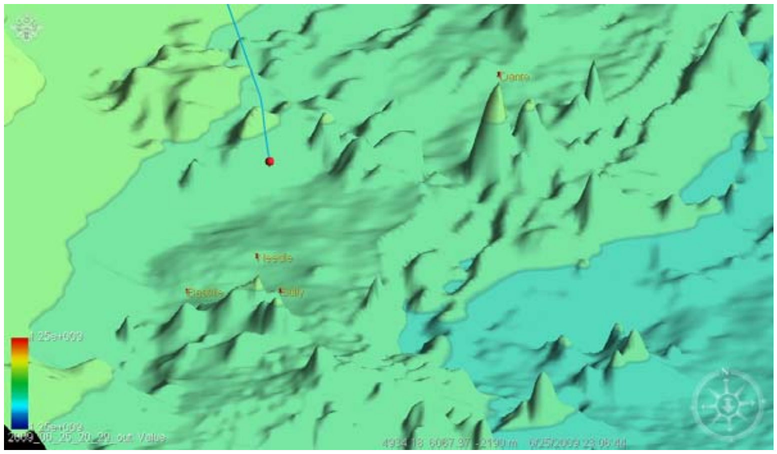


Figure 2.12.5. Overview of the site on descent (position of *Alvin* is red sphere).

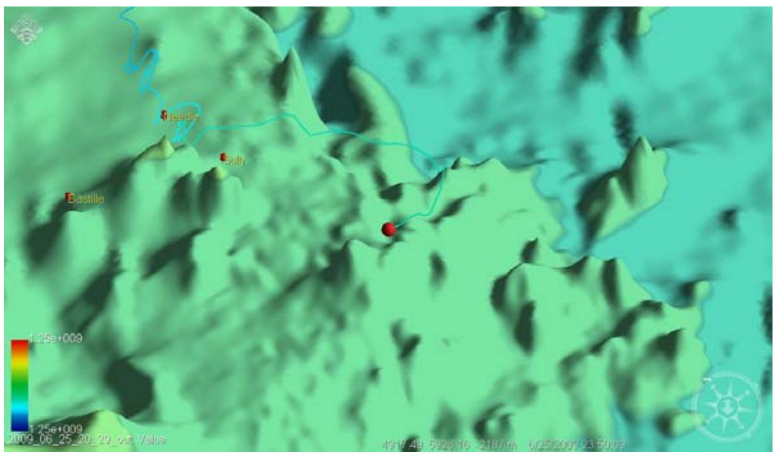


Figure 2.12.6. Navigational U-turn to find Bastille vent.

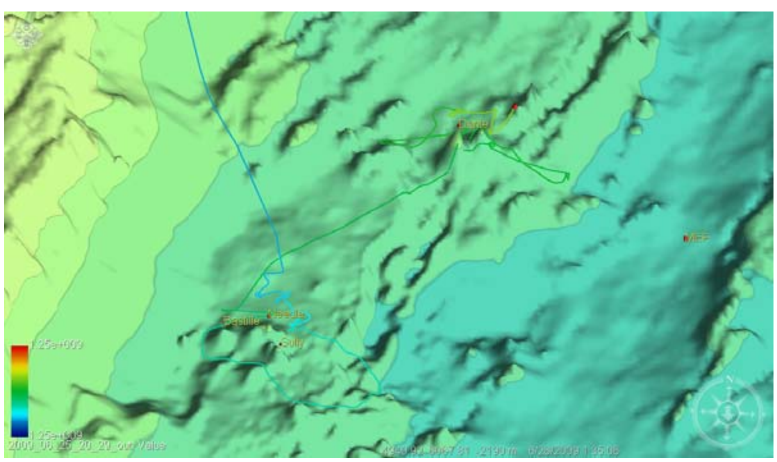


Figure 2.12.7. The path of *Alvin* on the bottom over the course of the dive.

2.13 Dive 4526: High Rise Field **June 26, 2009**

Pilot: Bruce Strickrott

Port Observer: Jim Holden

Starboard Observer: Helene Ver Eecke

Primary objectives: The goals of the dive were to collect co-localized low and high temperature fluids from Fairy Castle, Ventnor, Baltic, and Boardwalk vents.

Sample summary: 4 gas-tight fluid samples, 19 HFS fluid samples (8 filtered, 9 unfiltered, 2 sterivex filter), and 2 flow meter measurements.

Dive Summary:

The sub entered the water at 1500 UTC and landed on the bottom just west of the High Rise horst at 1613 (x:5744, y:8060, d:2153 m). Our goal was to head to the Fairy Castle vent first for sampling and then work our way north to the other vents. The location of Fairy Castle was inaccurate so we spent a bit of time looking for the structure. At 1637, we arrived at Fairy Castle (Fig. 2.13.1) and began collecting fluid samples. First we collected 329°C fluids in a filtered HFS piston, an unfiltered piston, and a gas tight sampler (x:5710, y:8137, d:2158 m, alt.:9.3 m, h:160°). We also took a flow meter measurement using the Germanovich flow meter (Fig. 2.13.2). At 1724, we repositioned the sub and collected low temperature diffuse fluids (18.2-28.9°C) using the HFS that included a filtered bag, two unfiltered bags, and a sterivex filter (x:5710, y:8137, d:2157 m, h:156°). We then headed west off of the horst to the western rise and Ventnor vent (Fig. 2.13.3). At 1821, we collected high temperature (332°C) fluids using a gas tight sampler, a filtered HFS piston, and an unfiltered piston and took another high temperature fluid flow measurement (x:5602, y:8201, d:2163 m, alt.:6.3 m, h:063°). At 1849, we repositioned the sub slightly to collect low temperature (20.8-21.0°C) diffuse fluids that consisted of a filtered HFS bag and an unfiltered bag (x:5602, y:8201, d:2163 m, alt.:6.0 m, h:067°).

We then departed this site and headed for the northern venting on the horst. At 1936, we arrived at Baltic vent (Fig. 2.13.4) and began collecting high temperature (306°C) fluids with a filtered and an unfiltered HFS bag and a gas tight sampler (x:5712, y:8220, d:2147, alt.:15.0 m, h:101°). As was the case for the Fairy Castle and Ventnor vents, we collected fluids from the same black smoker that was examined on the previous High Rise (dive #4516). At 1952, we repositioned the sub nearby and collected low temperature (20.8-23.3°C) fluids using a filtered and an unfiltered HFS bag (x:5712, y:8220, d:2147 m, alt.: 15.0 m, h:101°). At 2032, we then moved north to the Boardwalk vent (Fig. 2.13.5) and collected high temperature (340°C) fluids using a filtered and an unfiltered HFS piston and a gas tight sampler (x:5747, y:8303, d:2140 m, alt.:21.3 m, h:349°). At 2049, the sub was repositioned to collect low temperature (13.7-16.4°C) fluids using a filtered and an unfiltered HFS bag and a sterivex filter. We had to cut the filtering time to just 1 liter due to power limitations and left the bottom shortly after 2100.

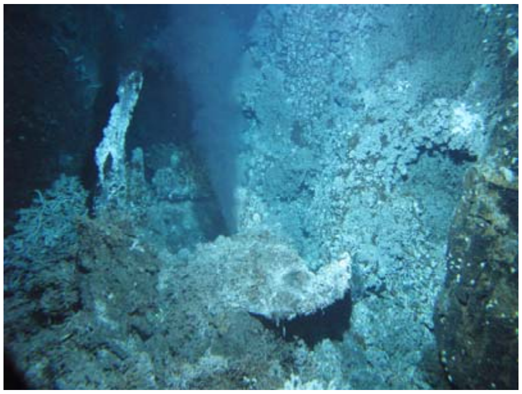


Figure 2.13.1. The site of high and low temperature fluid collection at Fairy Castle vent.

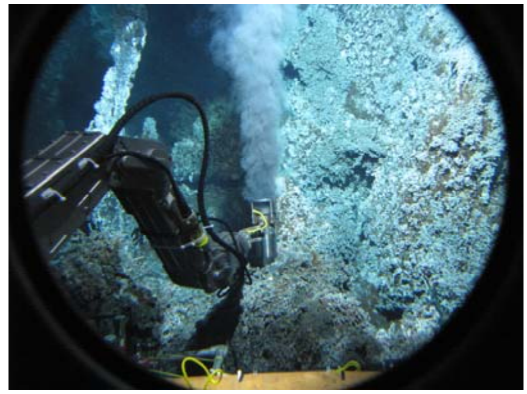


Figure 2.13.2. Flow meter measurement at Fairy Castle vent.

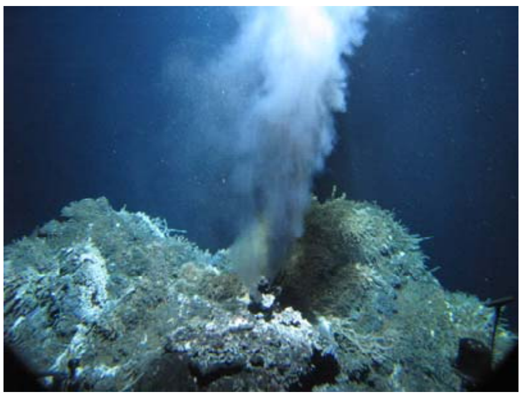


Figure 2.13.3. The site of high and low temperature fluid collection at Ventnor vent.

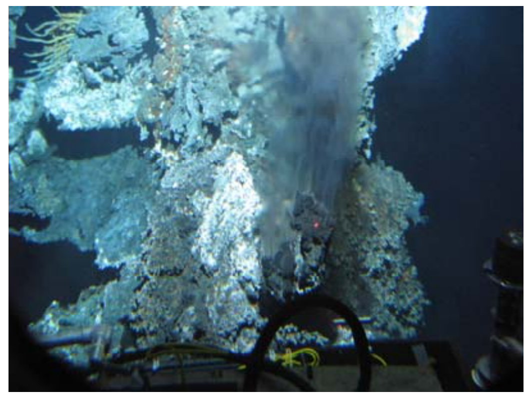


Figure 2.13.4. The site of high and low temperature fluid collection at Baltic vent.

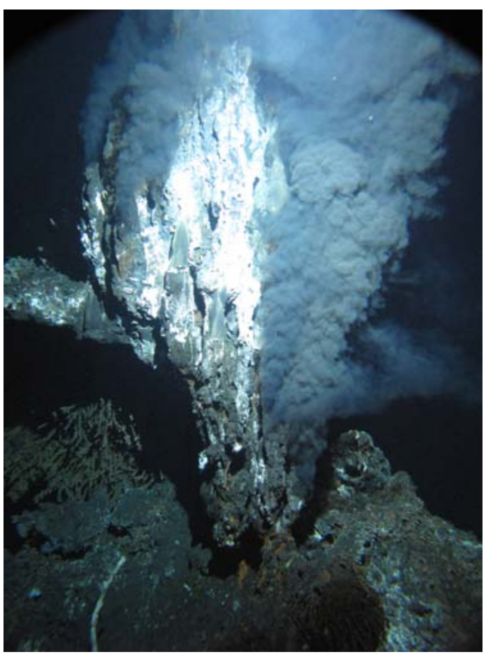


Figure 2.13.5. The site of high and low temperature fluid collection at Boardwalk vent.

3.0 Summary of non-dive operations

3.1 CTD operations (Sanjoy Som and Alden Denny)

The Conductivity- Temperature-Depth (CTD) instrument package was deployed following Alvin recoveries. Operations included i) vertical casts above sites of interest, ii) Tow-Yo's: short casts from ~250m above bottom to bottom and back with the ship moving with a constant velocity (usually 0.2 – 0.3 kts) and iii) Po-Go's: discrete vertical casts at tens of meters intervals to precisely locate a small vent field.

The CTD is composed of an instrument package surrounded by a 23 Niskin bottle rosette that can be remotely triggered to sample water at desired depths. The seabird instrument package allows live monitoring of depth, temperature, conductivity, average sound velocity, transmissivity, oxygen content, turbidity, salinity, and fluorescence. An altimeter on the rosette locks to within ~50m from the bottom to allow precise maneuvering at depth. We used temperature and transmissivity as our main proxies for plume detection. A typical plume would be visible by a coupled decrease in transmissivity and increase in temperature. Plume water samples were occasionally tested for methane and hydrogen content. An H_2/CH_4 ratio is a proxy for plume residence time (and thus how far one is from a vent).

Water was sampled for different analyses including

- Helium content
- Methane and hydrogen content
- Bacterial and viral counts
- ^{36}Chlorine isotopic measurements

CTD ops involved 12 separate casts:

M# are location numbers

Cast 1: Vertical Cast; Off-axis water samples: 47° 56′ 00′′N 129° 04′30′′W
-Comments: collect background water; depths sampled: 2300m, 1800m, 1300m, 800m, 300m, 100m.

Cast 2: Po-Go between Dante and Needles;
-Start: 47° 56.952′ N 129° 5.897′ W
-End: 47° 56.875′ N 129° 5.940′ W
-Comments: train operators in CTD operations

Cast 3: Tow-Yo between south of putative sulfide site and the Clague-dentified location
-Start: 47° 53.804′ N 129° 7.804′ W
-End: 47° 54.335′ N 129° 7.386′ W
-Comments: This Tow-Yo served as a reconnaissance mission for this previously unexplored site. Discrete and small plume signatures were detected at 3 sites and selected for future Po-Go exploration (casts 6-9).

Cast 4: Vertical Cast; Ashes Vent (Axial Volcano): 45° 56.014′ N 130° 0.841′ W

Cast 5: Vertical Cast; Castle Vent (Axial Volcano): 45° 55.569′ N 129° 58.825′ W

Cast 6: Vertical Cast; Southern putative sulfide site 1: 45° 59.326′ N 130° 1.637′ W

Cast 7: Vertical Cast; Southern putative sulfide site 2: 45° 55.001′ N 129° 59.624′ W

Cast 8: Po-Go at Clague-identified site 1;

-M1 (summit): 47° 53.972′ N 129° 7.667′ W
-M2: 47° 53.972′ N 129° 7.708′ W
-M3: 47° 53.972′ N 129° 7.747′ W
-M4: 47° 53.946′ N 129° 7.709′ W
-M5: 47° 53.946′ N 129° 7.668′ W
-M6: 47° 53.999′ N 129° 7.668′ W
-M7: 47° 53.972′ N 129° 7.628′ W
-Comments : enough of a signal to justify coming back, but nothing substantial
Tow-Yo between summit of the Clague-identified site 1 and site 2.
-M8 (start) : 47° 53.947′ N 129° 7.628′ W
-M12 (stop): 47° 54.107′ N 129° 7.564′ W
Po-Go at site 2
-M13: 47° 54.107′ N 129° 7.564′ W
-M14: 47° 54.164′ N 129° 7.536′ W
-M15: 47° 54.168′ N 129° 7.522′ W
-M16 : 47° 54.168′ N 129° 7.483′ W
-M17: 47° 54.168′ N 129° 7.562′ W
-Comments: No signal

Cast 9: Po-Go at Clague-identified site 1; re-baptized "Hookah" because of local plume detection!
-M1: 47° 54.329′ N 129° 7.382′W
-M2: 47° 54.356′ N 129° 7.423′ W
-M3: 47° 54.328′ N 129° 7.423′ W
-M4: 47° 54.301′ N 129° 7.422′ W
-M5: 47° 54.301′ N 129° 7.382′ W
-M6: 47° 54.355′ N 129° 7.382′ W
-M7: 47° 54.356′ N 129° 7.343′ W
-M8: 47° 54.331′ N 129° 7.345′ W
-M9: 47° 54.304′ N 129° 7.345′ W
-M10: 47° 54.344′ N 129° 7.404′ W
-Comments: strong plume signal at M1 towards M2 at 2155m (bottom at ~2260m). This highly suggests a local signature, because of the high H_2 and CH_4 found in the water column at M1 and M2. M9: detection of diffuse flow venting by temperature increase at <10m from bottom.
-Niskin bottles triggered and GC results for H_2 and CH_4:
Bottle 1 (M1), d=2155m, H_2 (NM) = 1.1, CH_4 (NM) = 11.4
Bottle 3 (M1), d=2095m, H_2 (NM) = 0.8, CH_4 (NM) = 27.1
Bottle 5 (M1), d=2041m, H_2 (NM) = 5.2, CH_4 (NM) = 241.1
Bottle 7 (M2), d=2144m, H_2 (NM) = 3.9, CH_4 (NM) = 110.5
Bottle 9 (M5), d=2225m, H_2 (NM) = 1.0, CH_4 (NM) = 3.4
Bottle 11 (M9), d=2236m, H_2 (NM) = 2.2, CH_4 (NM) = 3.2
-H_2 is a proxy for how long a plume has been in the water, since H_2 is consumed relatively quickly by biology. Such high concentrations of H_2 and CH_4 are unlikely signatures of Mothra, since it is > 4km away.

Cast 10: Vertical cast ; Hulk vent: 47° 57.024′ N 129° 5.762′ W
-Comments: sampled at regular interval: 2060m, 1500m, 1000m, 500m, 100m.

Cast 11: Full Tow-Yo of the Endeavour valley:
-Start (Sasquatch): 47° 59.843′ N 129° 4.080′ W
-Expected targets
-Salty Dawg: 47° 58.951′ N 129° 4.516′ W

-HiRise: 47° 57.985′ N 129° 5.279′ W
-MEF: 47° 56.948′ N 129° 5.886′ W
-Mothra: 47° 55.331′ N 129° 6.511′ W
-Stopped (Due to weather): 47° 58.847′ N 129° 4.596′ W

Cast 12: Continued Endeavour valley Tow-Yo.
-Start: 47° 58.847′ N 129° 4.596′ W
-0.2 C temperature anomaly ~70m above bottom at: 47° 58.474′N 129° 4.892′W (in between Salty Dawg and Hi-Rise). Bottle 3 was triggered upon finding the signal: H_2 (NM): 0.4; CH_4 (NM) 33.8
-End (HiRise): 47° 57.968′ N 129° 5.288′ W

3.2 Mooring deployments and recoveries at Axial Volcano

Objectives:
Biannual servicing of Nemo observatory in caldera of Axial Seamount. The observatory components requiring maintenance consisted of an array of four Ocean Bottom Hydrophones (OBH) and two Bottom Pressure Recorders (BPR).

Instrument Maintenance Required:
All instruments required fresh batteries and acoustic releases. All o-rings on all pressure cases were replaced. The OBHs also required new clock boards modified to provide a 1 pulse per second (1pps) signal for more accurate timing. One BPR required the replacement of a malfunctioning PCB. Two acoustic releases required battery replacement for redeployment to augment the four replacement releases, providing a total of six acoustic releases for the six moorings being deployed.

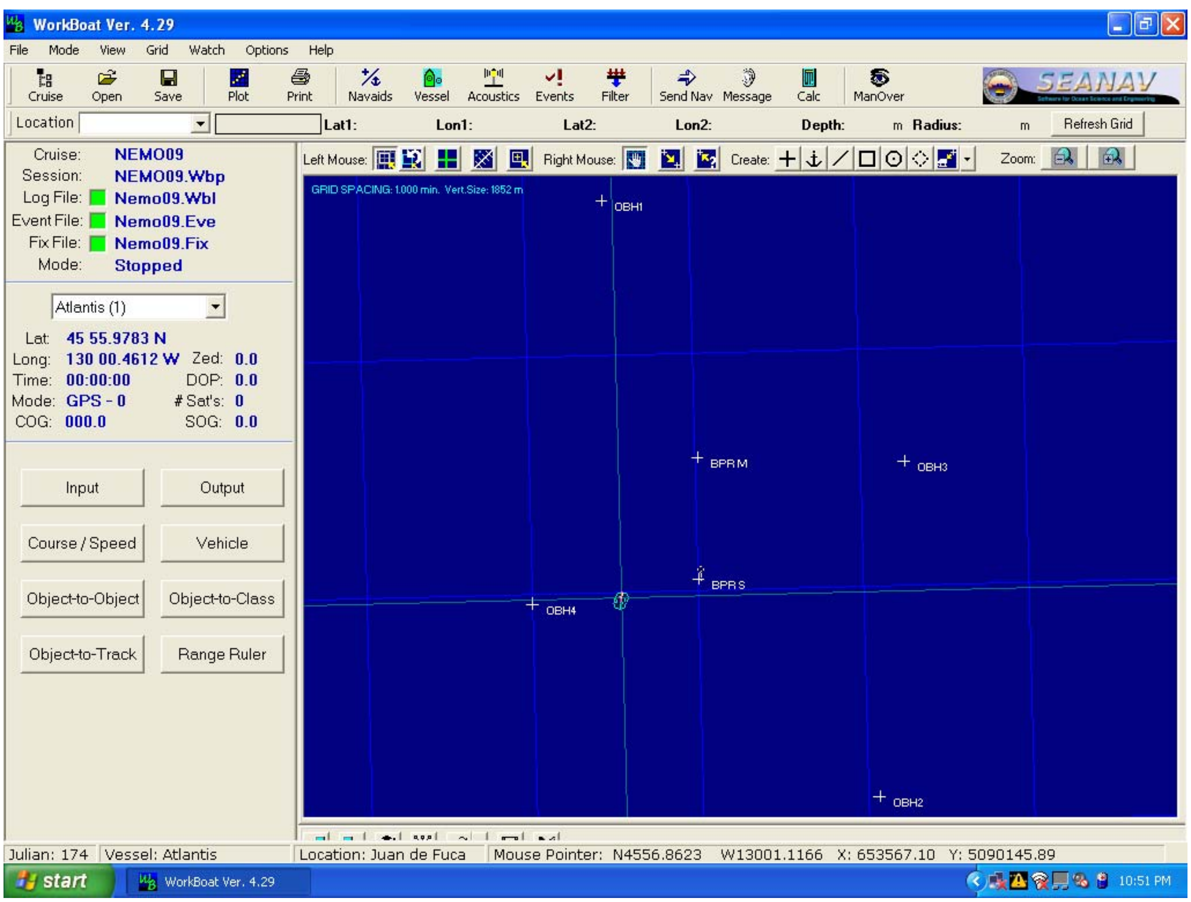
Mooring Operations:
All moorings were recovered on June 18, and were conducted around the schedule of DSV Alvin dive #4519. OBH 4 (N) was recovered before dive operations commenced. OBH 3 (W) was recovered midday during dive operations. Subsequent OBH recoveries occurred after recovery of the submersible, and were concluded at OBH 1 (S) by 17:45
BPR recoveries commenced upon the conclusion of the OBH recovery operations. Both BPRs were recovered by 23:30. The release on BPR middle reported a horizontal attitude before release.
All mooring operations were done over the starboard side of the Atlantis using the ship's crane and were deployed anchor first. A highly qualified Bosun, Patrick Hennesey and skilled deckforce of Kevin Threadgold, and Ronnie Whins augmented by SSSGs Allison Heater and Dave Sims accomplished all mooring operations in a safe and efficient manner, all instrumentation was recovered with no damage.
Instrument deployments were conducted over two nights of mooring operations. OBH 4, 3, and 2 were deployed on the evening of June 19, OBH 1 and both BPRs were deployed on the evening of June 20.
OBH 1 was damaged aboard ship. While OBH 2 was being deployed, someone who never identified themselves, broke the hydrophone off the OBH 1 pressure case, forcing the replacement of hydrophone before OBH could then be deployed.

Survey Operations:
All moorings had their positions surveyed using WorkBoat. The surveys were conducted during early morning hours, at the conclusion of CTD operations, to minimize impact on science, crew and ship's schedule. OBH 2 (S) and 3 (E) were surveyed in on the morning of June 20 between 05:00 and

06:30. OBH 4 (E), OBH 1 (N) and both BPR middle and south were surveyed in between 03:00 and 06:45 on June 21.

Mooring Information:

Instrument	OBH 1 (N)	OBH 2 (S)	OBH 3 (E)	OBH 4 (W)	BPR Middle	BPR South
Latitude	45°57.651N	45°55.114N	45°56.524N	45°55.960N	45°56.559N	45°56.047N
Longitude	130°00.521W	129°58.935W	129°58.736W	130°01.000W	129°59.984W	129°59.993W
Depth	1549 m	1535 m	1535 m	1436 m	1543 m	1541 m
Release S/N	33687	33686	33688	33685	31963	31961
Release Code	354317	354266	354334	354245	545527	545475
Disable Code	372505	372457	372543	372411	555513	555407
Enable Code	372474	372432	372526	372376	555462	555360
Intro Freq.	11.00 kHz	11.00 kHz	11.00 kHz	11.00 kHz	11.00 kHz	11.00 kHz
Reply Freq.	12.00 kHz	12.00 kHz	12.00 kHz	12.00 kHz	12.00 kHz	12.00 kHz



WorkBoat surveyed positions of deployed moorings.

3.3 Hydrothermal fluid sampling and shipboard analysis

3.3.1. *Sampling equipment*. Our tools for collecting hydrothermal fluids and particles included the PMEL Hydrothermal Fluid and Particle Sampler (HFPS), WHOI/DSOG's titanium major samplers, and titanium gas-tight samplers from the Lilley and Lupton labs. The HFPS was mechanically and electronically redesigned in 2007 and 2008 such that it now is configured to take a combination of 18 water samples in PVC piston or acrylic cylinders with collapsible plastic bags of Tedlar, an inert and impermeable polymer. Each water sampler has an in-line filter holder and check valve built into the lid. Approximately half of the water samples were set up with filters while the other half were unfiltered in order to allow culturing of microorganisms. During this cruise, we used either Millipore 47 mm diameter polycarbonate type HTTP 0.4 micron pore size membrane filters, or Millipore quartz fiber filters (Fisher catalog AGFA04700) combusted at 500°C for 10 hours. All filters were pre-weighed and stored in individual filter holders. Upon recovery, filters were suctioned to remove excess fluid, rinsed with a small volume of deionized water, suction dried, and air dried in petri slides.

During this expedition, we also used a large volume acrylic cylinder originally designed by Susan Lang to collect samples of approximately three liters volume for virus analysis by Rika Anderson. This cylinder was mounted next to the HFPS on *Alvin* and plumbed into the main manifold near the point where fluids enter from the intake hose. The large-volume sampler worked well and had no failures. PVC piston samplers have viton o-rings with Teflon guides and were lubricated with a small amount of inert Fluorolube high-temperature grease, the same compound used in titanium major samplers. Samplers were cleaned with hot water and laboratory detergent, hot water rinse, ethanol rinse, wiping with Kimwipes, deionized water rinse, and filtered deep seawater rinse (2,200 m for Endeavour, 1,525 m for Axial Volcano). Dead volumes were filled with filtered deep seawater collected during this cruise and kept in acid-cleaned containers. The manifold redesign was intended to minimize dead volumes and also to keep particles from accumulating near the inlets to sample containers. We collected a total of nine background seawater samples, mainly at the end of dives to test potential cross-contamination of diffuse fluid samples by previously collected high-temperature samples. Based on shipboard Si, H_2S, NH_3, and alkalinity measurements, the degree of cross-contamination is insignificant. In one case, a failed check valve from a high gas sample appears to have leaked gas into the manifold and into the background sample collected during ascent/decompression. Based on visual inspection of filter blanks from multiple dives, particle cross-contamination is also minimal. Titanium major and gas-tight samplers were used only in the discrete mode and were not attached to the HFPS manifold.

3.3.2. *Shipboard processing and analysis*. Gas-tight samples were stored in the lab until extracted by Leigh Evans. All other fluid samples were immediately put into the cold room or in an ice-bath until they could be processed. The primary sample processor was usually Kevin Roe, who would split the samples into their sub-containers and distribute them for analysis. At times, Dave Butterfield either shared or took over this role. Eric Olson analyzed all HFPS samples and RAS samples for H_2 and CH_4 by shipboard chromatography (detection limits for H_2 increased over the course of the cruise due to an increasingly noisy baseline). When a gas phase was present, both gas and liquid were analyzed. Gases were not analyzed on titanium major samples because they do not have effective seals to prevent fluid and gas exchange. Kevin Roe analyzed total H_2S using methylene blue method after Cline (1969). My Christensen measured pH with a Ross Sure-Flow electrode standardized daily with commercial pH buffers (3, 4, 7, 8), titrated samples for alkalinity with the Brinkmann Titrino automated titrator, and analyzed silica content on samples diluted in 0.02 N HCl (diluted by Kevin Roe during sample processing). Annie Bourbonnais analyzed all samples (excluding gas-tights) for NH_3 by spectrophotometry. We saved aliquots of all samples for nutrients (filtered, purged, frozen), major ions (filtered), and trace metals (acidified with SeaStar conc. HCl, 2% by volume) analysis on shore. Selected samples were saved for S, C, H, O, N, and Sr isotope analysis. Noah Lawrence-Slavas maintained the HFPS throughout the cruise.

3.3.3. *RAS setup and processing*. RAS time-series samplers were recovered during *Alvin* dives and brought on deck. After external cleaning, the sample bags were removed, valves closed, and stored on ice. Samples were weighed in the bags to determine volume of liquid. All samples were analyzed for gases, H_2S, pH, alkalinity, silica, and NH_3 on board. Aliquots for major ions, trace metals, and nutrients (frozen) were saved. The RAS instruments deployed in 2008 were all deployed with 47 mm diameter, 0.4 micron pore size HTTP polycarbonate membrane filters. RAS serial number 11072 (stainless steel frame) with Sonardyne beacon 16 was deployed at Marker 33 vent to start sampling noon UTC 9/1/2008 and then every 7 days, 5 hours, and 50 minutes until 8/7/2009, and has 1% HCl with 10 mg/liter Er tracer as a backflush. RAS serial number 11431.01 (titanium frame) was deployed on top of Lobo vent, also with HTTP filters. This RAS is not using backflush acid, and starts sampling at noon UTC on 9/7/2008 every 7 days, 5 hours, and 50 minutes thereafter. Sonardyne beacon 15 is attached to this RAS.

4.0 Preliminary description of sulfide samples

ALV4517-1703

X: 5052
Y: 6251
Z: 2198 mbsl
Alt: 0.9
F.G.: 0088-0099
Date: June 16, 2009

Small, inactive sulfide sample collected from sulfide rubble, east of Hulk, northern Main Endeavour field. The sample consists of 6 small pieces (max 5.5 cm). Sample shows strong mineralogical/chemical concentric zonation: outer surface is rust-orange coloured, 1 mm thick, with abundant thin fossil tube worms, filaments and living hydroids; a thin (up to 1 mm), discontinuous cream-coloured precipitate (bacterial?) occurs directly below outer oxidized surface. Below outer surface is a 2-3 mm green/grey Marcasite layer evenly distributed around the sample. The interior of the sample is composed of greenish to brownish grey, highly porous (~50%) fine-grained sulfide, likely a mixture of sphalerite/wurtzite with ~20% pyrite; porosity increases towards the interior and the colour grades from grey towards the exterior to a brown central conduit.

Sample was collected for Ra-226 dating at U. of Ottawa (Jamieson/Hannington).

ALV4517-1718

X: 5052
Y: 6247
Z: 2193 mbsl
Alt: 5.5
F.G.: 0125-0128
Date : June 16, 2009

Inactive sulfide from the eastern base of the Crypto vent complex, northern Main Endeavour Field. Sample is 11x7x12 cm. The sample has a distinct concentric mineralogical zonation. Outer surface has a well developed rust-orange oxidized layer (<1mm) with an underlying, irregular (up to 2 mm) buff-orange layer (bacterial?). This outer surface contains abundant fossilized tubeworms (typical diameter of 1 mm). Under the oxidized/bacterial layer is a 4-5 mm green-grey marcasite layer. The interior of the sample is composed of concentrically-zoned sulfides. Zones are defined by more dominant sphalerite/wurtzite (dark grey) or pyrite (greenish grey). Interior is highly porous, with porosity increasing towards the interior (40% along the exterior, up to 70% at the interior). Two primary fluid conduits are visible across the interior broken surface. The largest conduit is oval shaped (5.0 x 1.3 cm). A number of smaller (<1 cm) round conduits are located away from the central conduit.

Sample was collected for Ra-226 dating at U. of Ottawa (Jamieson/Hannington).

ALV4518-1836

X: 4999
Y: 6135
Z: 2179
Alt: 8.5
F.G.: 254-287
Date : June 17, 2009

Active sulfide collected north of Dudley, northern Main Endeavour Field. Small candelabra (est. 30 cm height) venting black smoke at 336 Celsius. Sample is light grey. Mineralogy is dominated by light and dark grey, fine-grained sphalerite/wurtzite and white anhydrite (up to 40-50%), with minor barite. An outer ~2 mm dark green/grey marcasite crust occurs around a single sphalerite/wurtzite-rich, sulfate-poor secondary flow channel that occurs outside of the main flow structure. Distribution of sulfide versus sulfate is irregular, with areas of 100% sulfate and others that are void of sulfate. A weak mineralogical repeating concentric zonation occurs with sulfate- and sulfide-rich zones (~5 mm thick). Porosity ranges from ~40% near the outside, up to 70% in the interior. Single irregular primary(?) flow channel ~2 cm diameter, lined with pink/grey fine anhydrite with 5% coating of up to 0.5 mm euhedral chalcopyrite. Minor secondary flow channels (> 1 cm) with thin chalcopyrite rinds. Anhydrite occurs in voids as 1-2 mm euhedral lathes, with possible minor barite.

Sample was collected for microbiological culturing and analyses (Ver Eecke/Holden, U. of Massachusetts), Ni-isotope biomarker analyses (Cameron, U. of Bristol), geochemical and petrographic analyses (Jamieson/Hannington, U. of Ottawa).

ALV4522-1725 **X: 6798** **Y: 2925** **Z: 1521** **Alt:** **F.G.: 187 - 195** **Date : June 21, 2009**	
Small (baseball-size) sulfide collected from the side of Diva, at Axial Volcano. The sample was collected near diffuse fluid (venting at 170 Celsius) and abundant tubeworms. The sample is composed primarily of grey, fine-grained wurtzite-sphalerite-pyrite mixture (50% porosity). One face of the sample appears to be the inner walls of an internal, hydrothermal fluid cavity within the original structure. The face is composed of mono-mineralic, framboidally-arranged, <= 1 mm cubic pyrite crystals. Outer-wall faces are covered in massive white anhydrite (up to 15 mm thick), with coarse 30% porosity. Another surface is covered by only 10% anhydrite (up to 1 mm thick) and shows evidence of minor bacterial surface growth. Sample was collected for Ni-isotope biomarker analyses (Cameron, U. of Bristol)	

ALV4522-1748 **X: 6755** **Y: 2944** **Z: 1507** **Alt:** **F.G.: 457 - 500** **Date : June 21, 2009**	
Large active spire collected from the base of El Guapo, within the caldera at Axial Volcano. Maximum measured temperature of venting fluid time of sample collection was 350 Celsius. The spire is void of any macrofauna. The intact sample was ~75 cm tall, 20 cm wide at its widest, and 10 cm across. Outer surface is covered in two distinct styles of sulfide mineralization: a soft, dark green, 'mushy' exterior, similar in texture and composition to interior 'mush' (see below), up to 5mm thick, porosity up to 70%, this outer coating is often locally oxidized (yellow/red rusty Fe-oxide, < 1 mm rough, soft surface), covering 15-20% of entire sample surface with associated white-yellow, probable bacterial mat (smooth, stringy coating on surface) on the oxidized surface; A harder, grey wurtzite-sphalerite-anhydrite-pyrite that is associated with internal high-T fluid	

conduits. A thin (max 2 mm) dark grey marcasite layer is locally present underneath pyrite-rich outer mush layer. Mineralogy and texture of interior of sample is controlled by proximity to high-T fluid conduits, which occur near the outer edges of the sample. High-T conduits are open orifices (up to 3 cm across), irregular oval in x-section, with an interior lining (up to 2 mm) of euhedral, prismatic chalcopyrite. High-T conduits have an associated zone of grey sulfide (likely wurtzite/sphalerite +/- pyrite) –anhydrite (+/- barite, silica) zone that extends to exterior of sample (max 3 cm). This zone is fine-grained and well mixed, with the exception of pods (max 3 cm across) of white, massive, coarse anhydrite (+/- barite?). The interior of the sample is dominated by dark-green, fine pyrite + chalcopyrite +/- wurtzite/sphalerite with a mushy texture and up to 80% porosity. This zone likely contained lower temperature, reduced-flow fluid. This zone constitutes over 50% of the sample by volume, but likely much less by mass.

Sample was collected for microbiological culturing and analyses (Ver Eecke/Holden, U. of Massachusetts), Ni-isotope biomarker analyses (Cameron, U. of Bristol), geochemical and petrographic analyses (Jamieson/Hannington, U. of Ottawa), fluid conduit dynamics (Germanovich, Georgia Tech), metagenomic sequencing (Dahle, U. of Washington/Bergen), laboratory bacterial culturing (Cameron, U. of Bristol), sulfide microbial fuel cell studies (Girguis, Harvard U.)

ALV4525-0134

X: 4991
Y: 6180
Z: 2193
Alt: 3.0
F.G.: 299-305
Date : June 25, 2009

Inactive sulfide from the base of Dante, Main Endeavour Field. Sample was broken off of larger piece that was too heavy to return to the surface with. The outer surface is red/brown (oxidized) 1 mm thick coating with fossil worm tubes. Under the oxidized layer is a 5 mm thick marcasite with minor wurtzite/sphalerite and anhydrite. The inside of the sample is dark grey/green, composed of fine-grained wurtzite/sphalerite and pyrite, with areas locally enriched in silica and anhydrite. The inside has variable porosity, ranging from 20-70% (bulk avg. ~45%). Multiple high-porosity flow channels are defined by irregular concentric texturally and mineralogically distinct zones that are either enriched or depleted in pyrite, relative to ZnS minerals.

Sample was collected for Ra-226 dating at U. of Ottawa (Jamieson/Hannington) and Ni-isotope biomarker analyses (Cameron, U. of Bristol).

Table A1. Summary of filtered samples collected using the hydrothermal fluid sampler for chemical analysis

Sample ID	Date	Time (UTC)	Fluid Temp.	Location	Local X	Local Y	Depth	Heading
4517-fluid-HFS-FP3	16 June 2009	1821	34.8°C	MEF – Hulk	5052	6243	2,198 m	035°
4517-fluid-HFS-FP1	16 June 2009	1904	299.6°C	MEF – Hulk	5053	6244	2,197 m	022°
4517-fluid-HFS-FP5	16 June 2009	1948	25.7°C	MEF – Hulk	5055	6248	2,189 m	117°
4519-fluid-HFS-FB16	18 June 2009	1714	15.6°C	Axial – Gollum	4138	3725	1,542 m	088°
4519-fluid-HFS-FP1	18 June 2009	1959	295°C	Axial – Inferno	4105	3719	1,539 m	137°
4519-fluid-HFS-FB18	18 June 2009	2023	8.9°C	Axial – Mushroom	4117	3734	1,541 m	315°
4519-fluid-HFS-FP5	18 June 2009	2046	3.6°C	Axial – Mushroom	4112	3743	1,542 m	253°
4520-fluid-HFS-FP3	19 June 2009	1835	24.7°C	Axial – Mkr113	6070	2550	1,521 m	035°
4520-fluid-HFS-FB16	19 June 2009	2010	10.2°C	Axial – 41 m S. of M113	6073	2510	1,521 m	028°
4520-fluid-HFS-FB17	19 June 2009	2053	11.6°C	Axial – 58 m S. of M113	6077	2492	1,521 m	013°
4520-fluid-HFS-FB20	19 June 2009	2307	2.7°C	Axial – Background sw	6662	3036	1,295 m	309°
4521-fluid-HFS-FP3	20 June 2009	1642	35.7°C	Axial – Mkr 33	6546	3685	1,520 m	131°
4521-fluid-HFS-FP7	20 June 2009	2004	9.7°C	Axial–16m from Mkr 33	6550	3691	1,521 m	060°
4521-fluid-HFS-FP5	20 June 2009	2021	4.4°C	Axial–16m from Mkr 33	6550	3691	1,521 m	084°
4521-fluid-HFS-FP1	20 June 2009	2051	2.7°C	Axial – Cloud	6560	3693	1,522 m	323°
4521-fluid-HFS-FB16	20 June 2009	2234	3.7°C	Axial – background sw	ascent	ascent	ascent	-
4522-fluid-HFS-FB16	21 June 2009	1626	17.7°C	Axial – Diva	6796	2926	1,520 m	123°
4522-fluid-HFS-FP1	21 June 2009	1712	166.7°C	Axial – Diva	6796	2926	1,520 m	089°
4522-fluid-HFS-FB17	21 June 2009	1845	34.2°C	Axial – Hermosa	6776	2944	1,519 m	223°
4522-fluid-HFS-FP7	21 June 2009	1958	288.9°C	Axial – El Guapo	6755	2944	1,507 m	047°
4523-fluid-HFS-FB19	22 June 2009	1656	16.7°C	MEF – Grotto	4954	6148	2,187 m	301°
4523-fluid-HFS-FP1	22 June 2009	1725	313.6°C	MEF – Grotto	4954	6148	2,187 m	301°
4523-fluid-HFS-FP3	22 June 2009	1838	164.9°C	MEF – Lobo	4934	6170	2,187 m	286°
4524-fluid-HFS-FB16	23 June 2009	1758	25.0°C	Mothra – Phang	4169	3310	2,277 m	014°
4524-fluid-HFS-FB18	23 June 2009	1851	25.8°C	Mothra – Phang	4169	3310	2,277 m	014°
4525-fluid-HFS-FP1	25 June 2009	0003	317.1°C	MEF – Bastille	4888	6010	2,194 m	106°
4526-fluid-HFS-FP1	26 June 2009	1643	312.2°C	High Rise – Fairy Castle	5710	8137	2,158 m	160°
4526-fluid-HFS-FB16	26 June 2009	1719	18.2°C	High Rise – Fairy Castle	5710	8137	2,157 m	156°
4526-fluid-HFS-FP3	26 June 2009	1822	330.5°C	High Rise – Ventnor	5602	8201	2,163 m	063°
4526-fluid-HFS-FB17	26 June 2009	1847	21.0°C	High Rise – Ventnor	5602	8201	2,163 m	067°

Sample ID	Date	Time (UTC)	Fluid Temp.	Location	Local X	Local Y	Depth	Heading
4526-fluid-HFS-FP5	26 June 2009	1934	303.7°C	High Rise – Baltic	5712	8220	2,147 m	101°
4526-fluid-HFS-FB18	26 June 2009	1950	20.8°C	High Rise – Baltic	5712	8220	2,147 m	101°
4526-fluid-HFS-FP7	26 June 2009	2029	338.8°C	High Rise – Boardwalk	5747	8303	2,140 m	349°
4526-fluid-HFS-FB19	26 June 2009	2051	15.7°C	High Rise – Boardwalk	5744	8305	2,141 m	045°

Sample summary:

34 filtered HFS fluid samples

Table A2. Summary of unfiltered samples collected using the hydrothermal fluid sampler for chemical and microbiological analyses

Sample ID	Date	Time (UTC)	Fluid Temp.	Location	Local X	Local Y	Depth	Heading
4517-fluid-HFS-UB19	16 June 2009	1817	33.2°C	MEF – Hulk	5052	6243	2,198 m	035°
4517-fluid-HFS-UP4	16 June 2009	1827	36.2°C	MEF – Hulk	5052	6243	2,198 m	035°
4517-fluid-HFS-UB21	16 June 2009	1850	13.7°C	MEF – Hulk	5052	6243	2,198 m	035°
4517-fluid-HFS-UP2	16 June 2009	1908	298.8°C	MEF – Hulk	5053	6244	2,197 m	022°
4517-fluid-HFS-UP6	16 June 2009	1954	26.5°C	MEF – Hulk	5055	6248	2,189 m	117°
4519-fluid-HFS-UB19	18 June 2009	1718	14.9°C	Axial – Gollum	4138	3725	1,542 m	088°
4519-fluid-HFS-UB22	18 June 2009	1723	14.1°C	Axial – Gollum	4138	3725	1,542 m	088°
4519-fluid-HFS-UB20	18 June 2009	1727	12.3°C	Axial – Gollum	4138	3726	1,542 m	088°
4519-fluid-HFS-UB21	18 June 2009	1830	14.3°C	Axial – Gollum	4142	3727	1,542 m	088°
4519-fluid-HFS-UP2	18 June 2009	2004	296°C	Axial – Inferno	4104	3718	1,539 m	137°
4520-fluid-HFS-UB24	19 June 2009	1840	26.5°C	Axial – Mk 113	6070	2550	1,521 m	036°
4520-fluid-HFS-UB23	19 June 2009	1926	34.3°C	Axial – Mk 113	6070	2550	1,521 m	036°
4520-fluid-HFS-UP4	19 June 2009	1931	34.1°C	Axial – Mk 113	6070	2550	1,521 m	036°
4520-fluid-HFS-UB22	19 June 2009	2005	10.5°C	Axial – 41 m S. of M113	6073	2510	1,521 m	027°
4520-fluid-HFS-UB21	19 June 2009	2059	11.8°C	Axial – 58 m S. of M113	6077	2492	1,521 m	013°
4521-fluid-HFS-UB19	20 June 2009	1729	34.0°C	Axial – Mk 33	6546	3685	1,521 m	129°
4521-fluid-HFS-UB21	20 June 2009	1733	33.9°C	Axial – Mk 33	6546	3685	1,521 m	129°
4521-fluid-HFS-UB22	20 June 2009	1736	34.0°C	Axial – Mk 33	6546	3685	1,521 m	129°
4521-fluid-HFS-UB20	20 June 2009	1741	33.8°C	Axial – Mk 33	6546	3685	1,521 m	129°
4521-fluid-HFS-UP6	20 June 2009	2010	4.9°C	Axial – 16 m from M33	6550	3691	1,521 m	063°
4521-fluid-HFS-UB23	20 June 2009	2042	5.7°C	Axial – Cloud	6560	3693	1,522 m	295°
4521-fluid-HFS-UB24	20 June 2009	2045	5.4°C	Axial – Cloud	6560	3693	1,522 m	322°
4521-fluid-HFS-UP4	20 June 2009	2229	3.3°C	Axial – background sw	ascent	ascent	ascent	-
4522-fluid-HFS-UB21	21 June 2009	1630	16.1°C	Axial – Diva	6796	2926	1,520 m	091°
4522-fluid-HFS-UP2	21 June 2009	1715	160.7°C	Axial – Diva	6796	2926	1,520 m	091°
4522-fluid-HFS-UB22	21 June 2009	1840	35.2°C	Axial – Hermosa	6776	2944	1,519 m	222°
4522-fluid-HFS-UB23	21 June 2009	1927	41.7°C	Axial – Hermosa	6776	2944	1,519 m	222°
4522-fluid-HFS-UP6	21 June 2009	1955	288.3°C	Axial – El Guapo	6755	2944	1,506 m	048°
4523-fluid-HFS-UB24	22 June 2009	1652	17.6°C	MEF – Grotto	4954	6148	2,187 m	301°
4523-fluid-HFS-UP2	22 June 2009	1729	324.4°C	MEF – Grotto	4954	6148	2,187 m	301°
4523-fluid-HFS-UP4	22 June 2009	1902	7.8°C	MEF – Lobo	4937	6172	2,188 m	276°

Sample ID	Date	Time (UTC)	Fluid Temp.	Location	Local X	Local Y	Depth	Heading
4523-fluid-HFS-UB23	22 June 2009	2037	8.4°C	MEF – Easter Island	4897	6016	2,193 m	306°
4523-fluid-HFS-UB22	22 June 2009	2043	9.1°C	MEF – Easter Island	4897	6016	2,193 m	306°
4524-fluid-HFS-UB21	23 June 2009	1812	24.3°C	Mothra – Phang	4169	3310	2,277 m	014°
4524-fluid-HFS-UB22	23 June 2009	1816	24.3°C	Mothra – Phang	4169	3310	2,277 m	014°
4524-fluid-HFS-UB20	23 June 2009	1822	21.3°C	Mothra – Phang	4169	3310	2,277 m	014°
4525-fluid-HFS-UP2	25 June 2009	0015	316.5°C	MEF – Bastille	4888	6010	2,194 m	106°
4525-fluid-HFS UB??	25 June 2009	0135	1.9°C	MEF – background sw	4988	6175	ascent	-
4526-fluid-HFS-UP2	26 June 2009	1648	315.7°C	High Rise – Fairy Castle	5710	8137	2,158 m	160°
4526-fluid-HFS-UB20	26 June 2009	1723	22.1°C	High Rise – Fairy Castle	5710	8137	2,157 m	156°
4526-fluid-HFS-UB21	26 June 2009	1727	24.6°C	High Rise – Fairy Castle	5710	8137	2,157 m	156°
4526-fluid-HFS-UP4	26 June 2009	1827	332.0°C	High Rise – Ventnor	5602	8201	2,163 m	063°
4526-fluid-HFS-UB23	26 June 2009	1851	20.8°C	High Rise – Ventnor	5602	8201	2,163 m	067°
4526-fluid-HFS-UP6	26 June 2009	1939	300.0°C	High Rise – Baltic	5712	8220	2,147 m	101°
4526-fluid-HFS-UB24	26 June 2009	1956	23.3°C	High Rise – Baltic	5712	8220	2,147 m	101°
4526-fluid-HFS-UP8	26 June 2009	2033	340.0°C	High Rise – Boardwalk	5747	8303	2,140 m	349°
4526-fluid-HFS-UB22	26 June 2009	2047	13.7°C	High Rise – Boardwalk	5744	8305	2,141 m	045°

Sample summary:

47 unfiltered HFS fluid samples

Table A3. Summary of sterivex filter samples collected using the hydrothermal fluid sampler for microbiological analyses

Sample ID	Date	Time (UTC)	Fluid Temp.	Location	Local X	Local Y	Depth	Heading
4517-fluid-HFS-St11	16 June 2009	1832	32.9°C	MEF – Hulk	5052	6253	2,198 m	035°
4519-fluid-HFS-St11	18 June 2009	1751	12.7°C	Axial – Gollum	4139	3728	1,542 m	088°
4519-fluid-HFS-St10	18 June 2009	1808	13.6°C	Axial – Gollum	4139	3728	1,542 m	088°
4520-fluid-HFS-St10	19 June 2009	1845	30.1°C	Axial – Mk 113	6070	2550	1,522 m	036°
4520-fluid-HFS-St11	19 June 2009	1904	33.2°C	Axial – Mk 113	6070	2550	1,522 m	036°
4520-fluid-HFS-St12	19 June 2009	2014	10°C	Axial – 41 m S. of M113	6073	2510	1,521 m	028°
4520-fluid-HFS-St13	19 June 2009	2104	11.6°C	Axial – 58 m S. of M113	6077	2492	1,521 m	014°
4521-fluid-HFS-St10	20 June 2009	1649	34.5°C	Axial – Mk 33	6546	3685	1,521 m	130°
4521-fluid-HFS-St11	20 June 2009	1710	34.1°C	Axial – Mk 33	6546	3685	1,521 m	129°
4521-fluid-HFS-St12	20 June 2009	2059	5.9°C	Axial – Cloud	6560	3693	1,522 m	324°
4521-fluid-HFS-St14	20 June 2009	2240	4.5°C	Axial – background sw	ascent	ascent	ascent	-
4522-fluid-HFS-St15	21 June 2009	1635	17.7°C	Axial – Diva	6796	2926	1,520 m	123°
4522-fluid-HFS-St10	21 June 2009	1904	40.4°C	Axial – Hermosa	6776	2944	1,519 m	223°
4523-fluid-HFS-St15	22 June 2009	1701	18.1°C	MEF – Grotto	4954	6148	2,187 m	301°
4523-fluid-HFS-St10	22 June 2009	1907	7.1°C	MEF – Lobo	4937	6172	2,188 m	281°
4523-fluid-HFS-St11	22 June 2009	2049	9.3°C	MEF – Easter Island	4897	6016	2,193 m	306°
4524-fluid-HFS-St10	23 June 2009	1828	24.0°C	Mothra – Phang	4169	3310	2,277 m	014°
4526-fluid-HFS-St10	26 June 2009	1731	28.9°C	High Rise – Fairy Castle	5710	8137	2,157 m	156°
4526-fluid-HFS-St13	26 June 2009	2104	16.4°C	High Rise – Boardwalk	5744	8305	2,141 m	045°

Sample summary:

19 sterivex filter samples

Table A4. Summary of major fluid samples for chemical analyses

Sample ID	Date	Time (UTC)	Fluid Temp.	Location	Local X	Local Y	Depth	Heading
4514-fluid-M16	14 Jun 2009	1650	2.5°C	MEF – Lobo	No nav.	No nav.	2,197 m	256°
4514-fluid-M10	14 Jun 2009	1650	2.5°C	MEF – Lobo	No nav.	No nav.	2,197 m	256°
4516-fluid-M20	15 June 2009	1954	349°C	High Rise – Godzilla	5769	8313	2137	127°
4516-fluid-M22	15 June 2009	2033	332°C	High Rise – Park Place	5736	8258	2149	123°
4516-fluid-M25	15 June 2009	2119	333°C	High Rise – Baltic	5743	8211	2147	095°
4516-fluid-M26	15 June 2009	2154	332°C	High Rise – Ventnor	5604	8196	2164	064°
4518-fluid-M25	17 June 2009	1847	336°C	MEF – Dante	4999	6135	2179	091°
4518-fluid-M26	17 June 2009	1847	336°C	MEF – Dante	4999	6135	2179	091°

Sample summary:

8 major fluid samples

Table A5. Summary of gas-tight fluid samples for gas chemistry analyses

Sample ID	Date	Time (UTC)	Fluid Temp.	Location	Local X	Local Y	Depth	Heading
4514-fluid-GT9	14 June 2009	1700	6°C	MEF – Lobo	No nav.	No nav.	2,197 m	256°
4514-fluid-GT12	14 June 2009	1704	6°C	MEF – Lobo	No nav.	No nav.	2,197 m	189°
4516-fluid-GT7	15 June 2009	1945	349°C	High Rise – Godzilla	5769	8131	2137	125°
4516-fluid-GT6	15 June 2009	1957	349°C	High Rise – Godzilla	5769	8131	2137	127°
4516-fluid-GT2	15 June 2009	2035	332°C	High Rise – Park Place	5736	8258	2149	123°
4517-fluid-GT5	16 June 2009	1920	304°C	MEF – Hulk	5053	6244	2197	022°
4518-fluid-GT9	17 June 2009	1850	336°C	MEF – Dante	4999	6135	2179	091°
4518-fluid-GT12	17 June 2009	1851	336°C	MEF – Dante	4999	6135	2179	091°
4519-fluid-GT17	18 June 2009		296°C	Axial – Inferno				
4521-fluid-GT18	20 June 2009		34°C	Axial – Mk 33				
4521-fluid-GT2	20 June 2009		6°C	Axial – Cloud				
4522-fluid-GT9	21 June 2009	1602	170°C	Axial – Diva	6796	2926	1,520 m	089°
4522-fluid-GT11	21 June 2009	1602	170°C	Axial – Diva	6796	2926	1,520 m	089°
4522-fluid-GT12	21 June 2009	1940	337°C	Axial – El Guapo	6755	2944	1,507 m	047°
4522-fluid-GT7	21 June 2009	1940	337°C	Axial – El Guapo	6755	2944	1,506 m	047°
4522-fluid-GT17	21 June 2009	1940	351°C	Axial – El Guapo	6755	2944	1,507 m	227°
4522-fluid-GT6	21 June 2009	1940	351°C	Axial – El Guapo	6755	2944	1,507 m	227°
4523-fluid-GT5	22 June 2009	1739	340°C	MEF – Grotto	4954	6148	2,187 m	300°
4523-fluid-GT18	22 June 2009	1845	296°C	MEF – Lobo	4934	6170	2,187 m	286°
4525-fluid-GT7	25 June 2009	0023	317°C	MEF – Bastille	4888	6010	2,194 m	106°
4525-fluid-GT11	25 June 2009	0026	317°C	MEF – Bastille	4888	6010	2,194 m	106°
4525-fluid-GT2	25 June 2009	0112	338°C	MEF – Dante	4965	6168	2,180 m	069°
4525-fluid-GT6	25 June 2009	0116	338°C	MEF – Dante	4965	6168	2,180 m	069°
4526-fluid-GT16	26 June 2009	1637	329°C	High Rise – Fairy Castle	5710	8137	2,158 m	160°
4526-fluid-GT18	26 June 2009	1821	332°C	High Rise – Ventnor	5602	8201	2,163 m	063°
4526-fluid-GT9	26 June 2009	1946	306°C	High Rise – Baltic	5712	8220	2,147 m	101°
4526-fluid-GT17	26 June 2009	2042	341°C	High Rise – Boardwalk	5747	8303	2,140 m	349°

Sample summary:

27 gas tight fluid samples

Table A6. Summary of biology samples

Sample ID	Date	Time (UTC)	Location	Local X	Local Y	Depth	Altitude	Heading
4517-worms	16 June 2009		MEF – Hulk	5055	6247	2189		084°
4519-worms	18 June 2009		Axial – Mushroom					
4520-suction-1	19 June 2009	1955	Axial – Mk113	6073	2510	1522		034°
4520-suction-2	19 June 2009	2130	Axial - 58m S. of M113	6065	2489	1521		022°
4521-worms-1	20 June 2009	2005	Axial – Cloud	6550	3691	1522		076°
4521-worms-2	20 June 2009	2010	Axial – Cloud	6550	3691	1522		069°
4521-worms-3	20 June 2009	2025	Axial – Cloud	6550	3691	1522		060°
4522-suction-1	21 June 2009	1731	Axial – Diva	6796	2926	1,520 m		091°
4522-worms-1	21 June 2009	1737	Axial – Hermosa	6776	2944	1,519 m		232°

Sample summary:

10 biology samples

Table A7. Summary of sulfide and basalt rock samples collected using *Alvin*

Sample ID	Date	Time (UTC)	Fluid Temp.	Location	Local X	Local Y	Depth	Heading
4517-extinct sulfide	16 June 2009	1704	-	MEF – N. of Hulk	5052	6249	2,197 m	-
4517-extinct sulfide	16 June 2009	1719	-	MEF – N. of Hulk	5052	6247	2,193 m	-
4517-basalt	16 June 2009	2016	-	MEF – N. of Hulk	5019	6273	2,195 m	314°
4518-active sulfide	17 June 2009	1835	336°C	MEF – Dante	4998	6136	2179	091°
4522-active sulfide-1	21 June 2009	1729	-	Axial – Diva	6796	2926	1520	091°
4522-active sulfide-2	21 June 2009	1940	351°C	Axial – El Guapo	6755	2944	1,506 m	227°
4525-extinct sulfide	25 June 2009	0134	-	MEF – Dante	4991	6180	2,193 m	013°

Sample summary:

2 active sulfides, 3 extinct sulfides, 2 basalts

Table A8. Summary of CTD water column samples using 10-liter Niskin bottles

Sample ID	Date	Time (UTC)	Location	Latitude	Longitude	Depth	Temp.	Trans. %
AT1547001-1 to -13	15 June 2009	0652	Background seawater	47° 56.000	-129° 4.300	2,300 m	1.83°C	78.00
AT1547001-14,15	15 June 2009	0705	Background seawater	47° 56.000	-129° 4.300	1,800 m	2.02°C	79.00
AT1547001-16,17	15 June 2009	0716	Background seawater	47° 56.000	-129° 4.300	1,300 m	2.70°C	79.00
AT1547001-18 ,19	15 June 2009	0727	Background seawater	47° 56.000	-129° 4.300	800 m	3.83°C	80.00
AT1547001-20,21	15 June 2009	0740	Background seawater	47° 56.000	-129° 4.300	300 m	5.93°C	81.00
AT1547001-22 ,23	15 June 2009	0747	Background seawater	47° 56.000	-129° 4.300	100 m	7.20°C	81.00
AT1547002-1,2	16 June 2009	0700	MEF – Dante	47° 56.952	-129° 5.897	2,197 m	3.00°C	75.6
AT1547002-3 to 5	16 June 2009	0922	MEF – Dante	47° 56.875	-129° 5.940	2,135 m	1.95°C	79.34
AT1547002-6	16 June 2009	0926	MEF – Dante	47° 56.875	-129° 5.940	1,950 m	1.93°C	79.45
AT1547002-7,8	16 June 2009	0928	MEF – Dante	47° 56.875	-129° 5.940	1,800 m	2.03°C	80.02
AT1547002-9,10	16 June 2009	0932	MEF – Dante	47° 56.875	-129° 5.940	1,600 m	2.25°C	80.17
AT1547002-11 to -14	16 June 2009	0932	MEF – Dante	47° 56.875	-129° 5.940	1,100 m	3.05°C	80.54
AT1547002-15 to -18	16 June 2009	0936	MEF – Dante	47° 56.875	-129° 5.940	600 m	4.49°C	80.95
AT1547002-19 to -22	16 June 2009	0940	MEF – Dante	47° 56.875	-129° 5.940	100 m	7.22°C	81.13
AT1547004-1,2	20 June 2009	0510	Axial – ASHES	45° 56.014	-130° 0.841	1,526 m	2.41°C	78.805
AT1547004-3	20 June 2009	0515	Axial – ASHES	45° 56.014	-130° 0.841	1,510 m	2.42°C	78.98
AT1547004-4,5	20 June 2009	0517	Axial – ASHES	45° 56.014	-130° 0.841	1,475 m	2.44°C	79.22
AT1547004-6,7	20 June 2009	0519	Axial – ASHES	45° 56.014	-130° 0.841	1,425 m	2.48°C	79.40
AT1547004-8,9	20 June 2009	0523	Axial – ASHES	45° 56.014	-130° 0.841	1,374 m	2.48°C	79.40
AT1547004-10,11	20 June 2009	0526	Axial – ASHES	45° 56.014	-130° 0.841	1,324 m	2.65°C	79.61
AT1547004-12,13	20 June 2009	0529	Axial – ASHES	45° 56.014	-130° 0.841	1,224 m	2.87°C	79.84
AT1547004-14,15	20 June 2009	0534	Axial – ASHES	45° 56.014	-130° 0.841	1,124 m	3.12°C	79.99
AT1547004-16 to -18	20 June 2009	0540	Axial – ASHES	45° 56.014	-130° 0.841	1,025 m	3.39°C	80.18
AT1547004-19,20	20 June 2009	0543	Axial – ASHES	45° 56.014	-130° 0.841	924 m	3.66°C	80.25
AT1547004-21,22	20 June 2009	0553	Axial – ASHES	45° 56.014	-130° 0.841	308 m	4.97°C	80.93
AT1547004-23	20 June 2009	0602	Axial – ASHES	45° 56.014	-130° 0.841	99 m	7.58°C	81.24
AT1547005-1,2	20 June 2009	0812	Axial – Castle	45° 55.569	-129° 58.824	1,505 m	2.40°C	79.38
AT1547005-3 to -5	20 June 2009	0815	Axial – Castle	45° 55.569	-129° 58.824	1,474 m	2.42°C	79.06
AT1547005-6,7	20 June 2009	0817	Axial – Castle	45° 55.569	-129° 58.824	1,425 m	2.45°C	79.73
AT1547005-8,9	20 June 2009	0821	Axial – Castle	45° 55.569	-129° 58.824	1,375 m	2.56°C	79.84
AT1547005-10,11	20 June 2009	0824	Axial – Castle	45° 55.569	-129° 58.824	1,324 m	2.63°C	79.94

Sample ID	Date	Time (UTC)	Location	Latitude	Longitude	Depth	Temp.	Trans. %
AT1547005-12,13	20 June 2009	0826	Axial – Castle	45° 55.569	-129° 58.824	1,275 m	2.73°C	79.99
AT1547005-14,15	20 June 2009	0828	Axial – Castle	45° 55.569	-129° 58.824	1,175 m	2.92°C	80.18
AT1547005-16,17	20 June 2009	0832	Axial – Castle	45° 55.569	-129° 58.824	1,075 m	3.18°C	80.33
AT1547005-18,19	20 June 2009	0837	Axial – Castle	45° 55.569	-129° 58.824	975 m	3.45°C	80.41
AT1547005-20,21	20 June 2009	0845	Axial – Castle	45° 55.569	-129° 58.824	500 m	4.94°C	81.21
AT1547005-22,23	20 June 2009	0855	Axial – Castle	45° 55.569	-129° 58.824	100 m	7.68°C	81.03
AT1547006-1,2	21 June 2009	0605	Axial – CASM	45° 59.326	-130° 1.637	1,562 m	2.34°C	78.96
AT1547006-3,4	21 June 2009	0609	Axial – CASM	45° 59.326	-130° 1.637	1,525 m	2.38°C	79.11
AT1547006-5,6	21 June 2009	0612	Axial – CASM	45° 59.326	-130° 1.637	1,500 m	2.37°C	79.27
AT1547006-7,8	21 June 2009	0616	Axial – CASM	45° 59.326	-130° 1.637	1,451 m	2.39°C	79.37
AT1547006-9,10	21 June 2009	0619	Axial – CASM	45° 59.326	-130° 1.637	1,400 m	2.47°C	79.56
AT1547006-11,12	21 June 2009	0622	Axial – CASM	45° 59.326	-130° 1.637	1,350 m	2.60°C	79.68
AT1547006-13,14	21 June 2009	0625	Axial – CASM	45° 59.326	-130° 1.637	1,300 m	2.72°C	79.82
AT1547006-15,16	21 June 2009	0630	Axial – CASM	45° 59.326	-130° 1.637	1,200 m	2.95°C	80.05
AT1547006-17,18	21 June 2009	0636	Axial – CASM	45° 59.326	-130° 1.637	1,000 m	3.31°C	80.26
AT1547006-19,20	21 June 2009	0647	Axial – CASM	45° 59.326	-130° 1.637	500 m	4.70°C	80.95
AT1547006-21 to23	21 June 2009	0658	Axial – CASM	45° 59.326	-130° 1.637	100 m	7.58°C	81.18
AT1536007-1,2	21 June 2009	0907	Axial – Vixen	45° 55.001	-129° 59.624	1,521 m	2.30°C	79.18
AT1536007-3,4	21 June 2009	0912	Axial – Vixen	45° 55.001	-129° 59.624	1,475 m	2.39°C	79.40
AT1536007-5,6	21 June 2009	0915	Axial – Vixen	45° 55.001	-129° 59.624	1,425 m	2.48°C	79.72
AT1536007-7,8	21 June 2009	0917	Axial – Vixen	45° 55.001	-129° 59.624	1,375 m	2.56°C	79.84
AT1536007-9,10	21 June 2009	0922	Axial – Vixen	45° 55.001	-129° 59.624	1,325 m	2.64°C	79.91
AT1536007-11,12	21 June 2009	0924	Axial – Vixen	45° 55.001	-129° 59.624	1,276 m	2.74°C	79.99
AT1536007-13,14	21 June 2009	0928	Axial – Vixen	45° 55.001	-129° 59.624	1,201 m	2.90°C	80.15
AT1536007-15,16	21 June 2009	0932	Axial – Vixen	45° 55.001	-129° 59.624	1,100 m	3.14°C	80.31
AT1536007-17,18	21 June 2009	0935	Axial – Vixen	45° 55.001	-129° 59.624	1,000 m	3.39°C	80.39
AT1536007-19,20	21 June 2009	0947	Axial – Vixen	45° 55.001	-129° 59.624	500 m	4.91°C	81.91
AT1536007-21 to23	21 June 2009	0956	Axial – Vixen	45° 55.001	-129° 59.624	100 m	7.56°C	81.31

Sample summary:

59 Niskin water column samples