NSF-UNOLS Early Career Training Cruise Opportunity
East Pacific Rise 9° 50'N – December 2018 Investigating Volcanic, Hydrothermal and Biological Phenomena Associated with New Eruptions: Using AUV *Sentry* Near-bottom Mapping and *Alvin* Diving

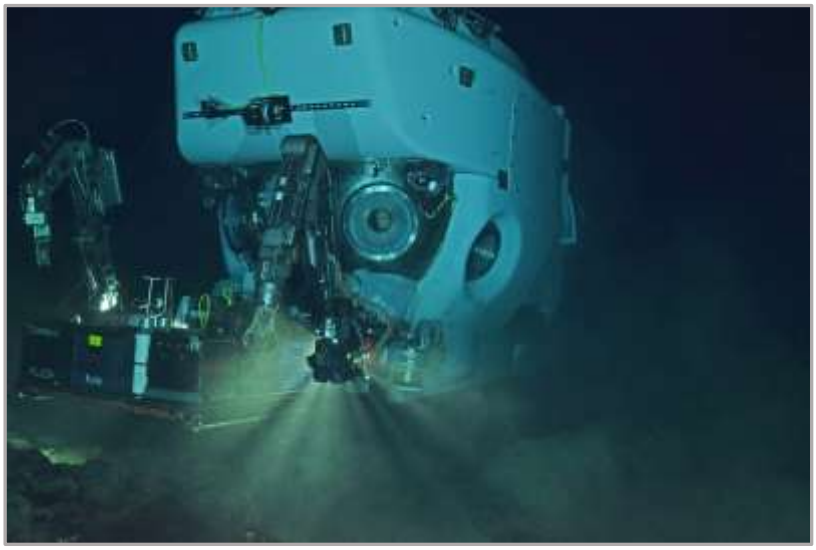


photo c/o Woods Hole Oceanographic Institution

To: Early Career Scientists in US Universities (including, early career faculty and post-docs)

From: Trish Gregg, Dan Fornari, Mike Perfit, Dorsey Wanless and UNOLS DESSC Committee (Anna-Louise Reysenbach)

Date: April 9, 2018

Subject: Opportunity for Early Career Scientist (ESC) at-sea experience on RV *Atlantis* With *Alvin* and AUV *Sentry* at East Pacific Rise (EPR) 9 50'N – December 3-21, 2018

Applicant Requirements:
UNOLS is seeking applications from early career scientists at U.S. universities who are interested in participating in an oceanographic research cruise that will continue an investigation of a chain of seamounts west of the East Pacific Rise at 8° 20' N followed by a detailed survey the East Pacific Rise ~ 9° 50' N that last erupted in 2005-2006. The cruise will take place aboard RV *Atlantis* Dec. 3-21, 2018, departing Manzanillo, MX and returning to San Diego, CA. The primary ECS objective will involve hands-on instruction on conducting deep-submergence vehicle-based field research. New faculty and post-docs are welcome to apply. It may be possible to accommodate graduate students; however, this will depend on the applicant pool and disciplinary breadth. A maximum of 10 applicants will be selected to participate on the cruise and others may be selected for

shore-based collaboration as there will be daily ship/shore and reverse communications capabilities via increased satellite bandwidth on the ship for the cruise duration.

Applicants should submit the following application materials via the following link by **May 15, 2018**.

https://www.surveymonkey.com/r/2018NSF-UNOLS-East-Pacific-Rise-CSW

You will be requested to upload a **single PDF document that contains the following**:
(Note: PDF file should be named using the following format: "LASTNAME_ECSapplicant")

2-page NSF-style CV

2-page letter summarizing your interest in participating in the ECS cruise. The letter should include:

- Your research background, including any previous cruise experience,
- The type of data you are interested in acquiring that relates to EPR volcanic/hydrothermal processes,
- The type of samples you would require for your work,
- Whether you have existing funding that would cover sample analyses and/or your participation in the ~2 week at-sea cruise (including travel and salary). Note: Modest travel and cruise-related costs may be able to be provided for ECS participants.

Final decisions on applicant selection will be made by June 30, 2018. If you have questions about the application process or the cruise program, please send an email to the following program leads:

Dr. Daniel Fornari: dfornari@whoi.edu
Dr. Patricia Gregg: pgregg@illinois.edu
Dr. Dorsey Wanless: dwanless@boisestate.edu
Dr. Michael Pefit: mperfit@ufl.edu

General Logistic Plan for Field Program:
The ECS cruise will be primarily accomplished in the last 4 days on station during a field program led by Trish Gregg, Dan Fornari, Mike Perfit and Dorsey Wanless. The first 6 days of the cruise (tentatively Dec. 3-9, 2018), will be devoted to transit from Manzanillo, MX to a field area near 8° 20'N, west of the EPR axis to investigate seamounts that are the focus of an NSF funded research program. 4 *Alvin* dives and 3 *Sentry* AUV dives will be carried out at the 8° 20'N area. ECS participants will be involved in the field data acquisition efforts during the seamount dives to learn about how to plan and execute deep-submergence sampling and mapping using *Alvin* and *Sentry*; information they can apply to the EPR dives that will follow the 8° 20'N seamount work.

On Dec. 9, the ship will transit overnight from 8° 20'N to the 9° 50'N field area and commence *Sentry* AUV mapping (3-4 *Sentry* dives are possible). The aim is to determine whether new lava channels are present indicating a volcanic eruption has occurred since the last known EPR eruption in 2005-2006 (e.g., Tolstoy et al., 2006, 2008; Cowen et al., 2007; Soule et al., 2007; Fundis et al., 2010, Rubin et al., 2012; Fornari et al, 2012; Tan et al., 2016). Based on real-time, at-sea analysis of those data (including possible shore-based analysis by some collaborators), 4 *Alvin* dives will be planned to focus on collecting site specific samples of volcanic rocks, hydrothermal fluids and chimney samples, and macro and microbiological samples in the 9° 50'N EPR area. Other types of sample acquisition and data collection will be considered based on the research objectives of the ECS participants and shore-based collaborators. RV *Atlantis* will arrive in San Diego, CA on the morning of Dec. 20, and a 1-day post-cruise 'Science Forum' will be held at a public venue in San Diego, in conjunction with colleagues at Scripps Institution of Oceanography that will include science presentations and an afternoon of public outreach and visits by the public to see UNOLS ships and deep-submergence vehicle systems.

Background Information:

The attached summary outlines the key aspects of recent EPR volcanism, the justification for suspecting that an eruption may have occurred since the last documented eruption in 2005-2006, and the types of studies that relate to volcanic and hydrothermal phenomena caused by submarine eruptions. Additionally, applicants should also refer to the 2012 Oceanography paper that summarizes EPR Ridge2000 research at the 9° 50'N area over the past few decades (**Fornari et al., 2012; The East Pacific Rise between 9°N and 10°N: Twenty-five years of integrated, multidisciplinary oceanic spreading center studies. Oceanography 25(1):18–43**)

1. Science motivation: Two historic volcanic eruptions at the East Pacific Rise (EPR) crest near 9° 50'N ~14 years apart – 1991-92 and 2005-06: has there been a new eruptive phase?

During the past ~15 years there have been major advancements in our understanding of mid-ocean ridge (MOR) volcanic, hydrothermal, geochemical and biological processes, and the interconnected nature of causal phenomena involved in oceanic crustal generation and evolution. These new guiding concepts of MOR processes, and how they relate to magmatic and volcanic events, have been nurtured and accelerated by focused studies at various MOR sites through the RIDGE and Ridge2000 NSF-sponsored programs [Fornari et al., 2012 – R2K volume Introduction]. A key enabling factor that has led to the new insights are the time-series nature of the experiments and recorded data that enable the 4-D aspects of the phenomena to be resolved and correlated. A few key examples of these new findings related to the East Pacific Rise (EPR) 9° 50'N area are (also - see the extensive reference list attached to this memo):

- direct relationships between tidal triggering of earthquakes and possibly volcanic eruptions [e.g., Stroup et al., 2007, 2009, Tolstoy et al., 2008];
- relationship between eruption volume, lava chemistry and the axial melt lens as imaged using 3D seismics [e.g., Carbotte et al., 2012; Goss et al., 2010];
- catastrophic impact of magmatic intrusion and eruption on portions of the hydrothermal plumbing as resolved by time-series temperature recorders in some of the vents (e.g., M-vent),
- deducing water-rock reaction zone dynamics through time series sampling of high-T hydrothermal fluids;
- formation of lava channels as a primary distribution mechanism to transport lava erupted in the axial trough out to several kilometers from the axis;
- recognition of the association between H_2, S and Fe oxidizing microbes and seafloor eruptions and the intricate biogeochemical processes occurring subseafloor and within vent chimneys;
- estimates of heat flux associated with MOR venting and partitioning between high- and low-T venting;
- and many more significant findings that have propelled MOR studies into the 21st century and helped foster the recognition of the importance of observatory-type studies such as those now being carried out by the OOI-RCN at Axial Seamount [e.g., Kelley et al., 2014].

In an effort to continue some of the time series experiments, RV *Atlantis*, *Alvin* and AUV *Sentry* will conduct ~4-days of *Sentry* AUV surveying and *Alvin* diving at the EPR 9° 50'N area to investigate whether there has been a suspected recent volcanic eruption at the EPR 9°50'N ISS site [Fornari et al., 2012]. Known, historic eruptions at this site are documented to have occurred in 1991-92 and again in 2005-06 [e.g., Haymon et al., 1993; Von Damm et al., 1995; Gregg et al., 1996; Tolstoy et al., 2006, 2008; Rubin et al., 2006, 2008, 2012; and Fornari et al., 2012 and references therein]. While there continues to be active discussion in terms of the nature and duration of the 2005-06 EPR eruptions [e.g., Tolstoy et al., 2006; Cowen et al., 2007; Rubin et al., 2006, 2008, 2012; Dziak et al., 2009; Tan et al., 2016], there is no question in regards to the definitive, mapping and observational-based data sets that unequivocally delimit the eruption area and emplacement mechanisms [e.g., Soule et al., 2007, Fundis et al., 2010; Fornari et al., 2012]. One of the key datasets used to corroborate visual and deep-sea camera (*TowCam*) observations was the resurveying of the EPR axis between ~9° 48'-52'N with deep-towed sidescan sonar (DSL-120 kHz system, White and Soule, see Figure 1). Those data, at ~2m

pixel resolution, clearly portray the extensive networks of lava channels that served to distribute the 2005-06 flows away from the axial summit trough (AST), where most if not all of the primary eruptive vents were located for all historic, documented eruptions.

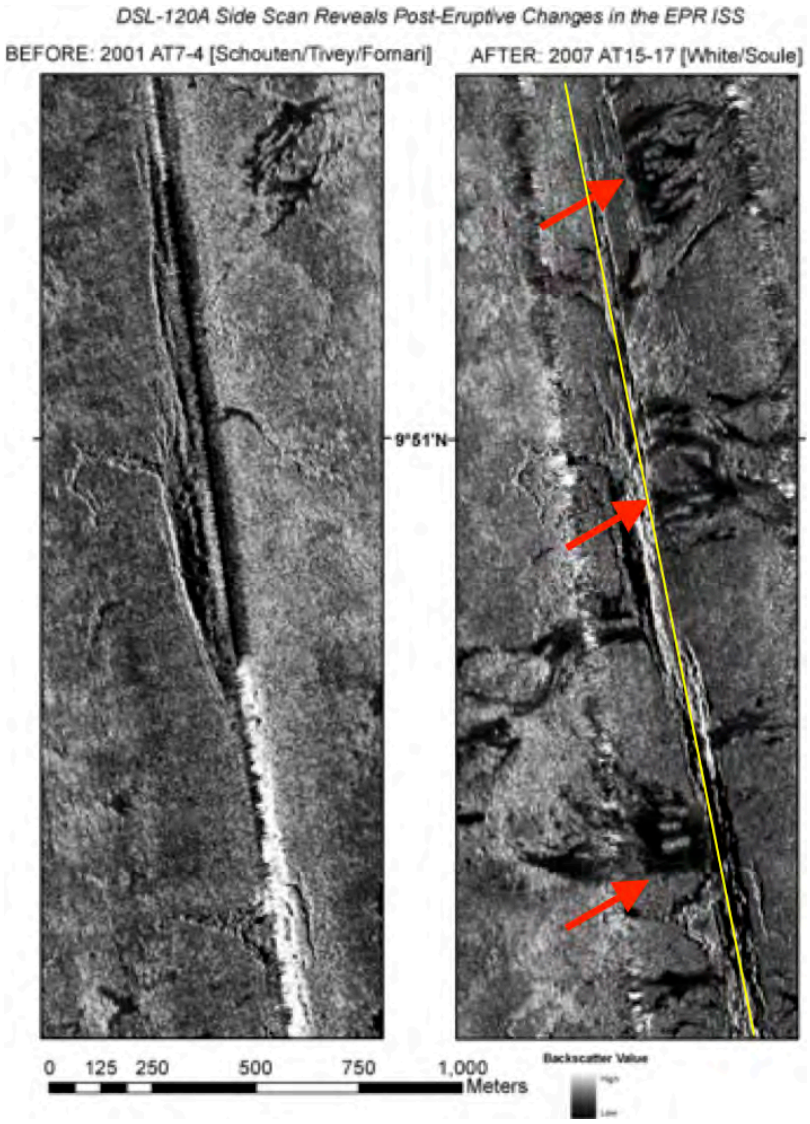


Figure 1. Pre- and post-2005-06 eruption DSL-120 kHz sidescan sonar images acquired in 2001 (left) and 2007 (right), which clearly delineate the new channels (dark curvilinear features {low reflectivity} – red arrows show major channel areas) that served to distribute the 2005-06 lava flows away from eruptive vents in the axial summit trough (thin yellow line). See Figure 5 for area covered by these sidescan images.

2. Observational evidence for possible "new" (post-2006) lava flows and re-activity of hydrothermal venting at the EPR 9°50'N area

Based on observations and preliminary interpretations from four *Alvin* and one *Jason* ROV cruise to the EPR in 2013, 2014, 2016 and Spring 2017, it appears that parts of the AST in the 9° 50'N area may have experienced recent (i.e., post 2005-06) eruptions. These findings relate primarily to both observer and Alvin pilot assessments of the following key environmental parameters at the 9° 50'N area.

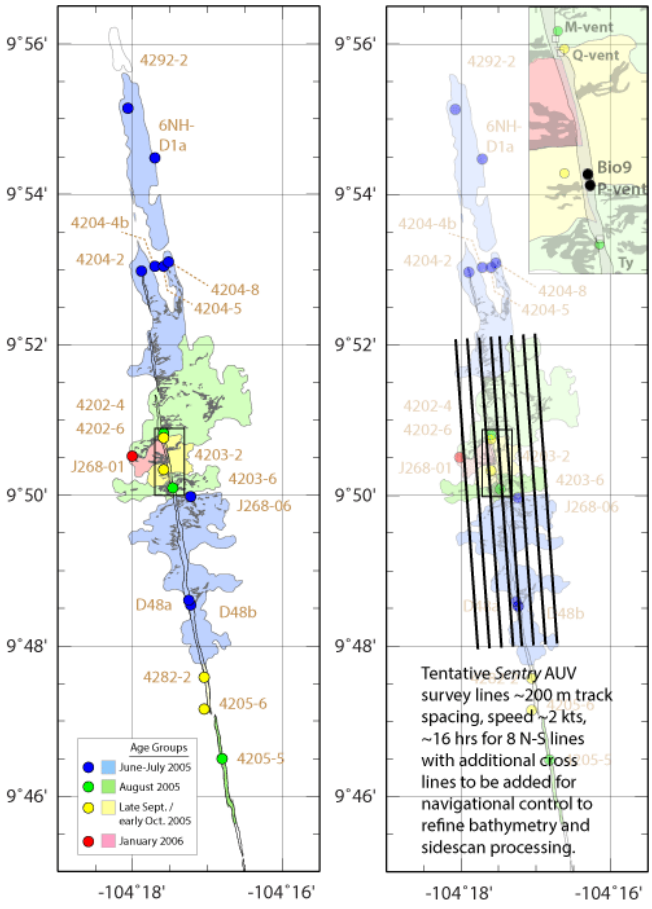


Figure 2. Po age-dating from summary by Rubin et al. [2006, 2008; 2012] showing location of dated samples from the 2005-06 eruption, and outline of lava flow lobes from observational data [Soule et al., 2007; Fundis et al. 2010] (left). (right) same base map showing extent and location of proposed Sentry AUV survey lines for the initial 24hr dive to map the EPR crest out to ~1km from the AST on both sides of the axis, over the main area where the EPR has erupted previously.

• **New Lava Flows?** - There is evidence for suspected 'new' / recent lava flows in the AST based on 2017 *Alvin* dive observations by G. Luther's group (U. Delaware) in the Ty/Io vent area (see Figures 2-3 for vent locations). Both observers and *Alvin* pilots (P. Hickey) highlighted the extreme glassiness of the flows (corroborated by inspection of hand samples of lava with lustrous/iridescent sheen and pristine glass), and that Ty/Io vent structures are no longer there (i.e., perhaps buried by recent flows?).

• **High-T venting** at Bio9 and P vents (see Figures 2-3 for vent locations), continue to be very active through spring 2017, with low-chlorinity fluid compositions at ~50% seawater values (suggesting they are vapor-phase), high temperatures (~370+°C), and abundant microbial and diffuse flow on the vent structures (preliminary data from both S. Sievert and J. Seewald – WHOI, and G. Luther – U. Delaware). These vents are thought to directly overlie magmatic feeders that have erupted lava during previous historic eruptions [Fornari et al., 2012]. While no 'new' lava has been observed in this area, clearly the vent activity and fluid temperatures and compositions suggest continued, direct subsurface access to 'hot'rock at shallow crustal levels.

• **M vent fluid temperature history pre-2005, impact of 2006 eruption and subsequent reactivation** - M-vent, located on the east wall of the axial trough of the EPR (Figure 1),

has been monitored and sampled since 1992 [Fornari et al., 1998a]. Data from an autonomous vent fluid temperature logger (HOBO™ - MISO logger – see http://www.whoi.edu/page.do?pid=17623) provide the most continuous record of vent temperature behavior pre- and post-eruption from April 2004 to late February 2006.

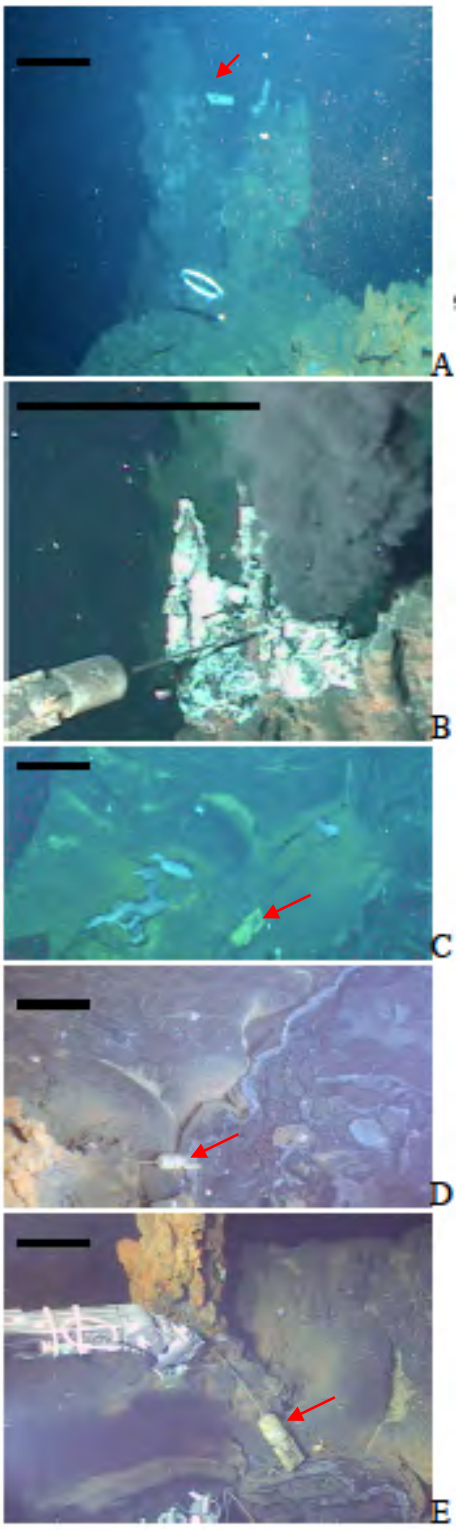
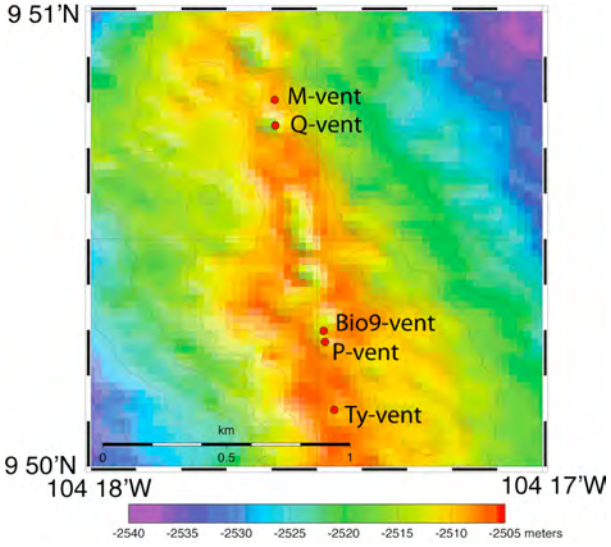


Figure 3. (bottom) Multibeam sonar map of the East Pacific Rise (EPR) axis showing location of high-temperature hydrothermal vents monitored using HOBO™ fluid temperature loggers and sampled using the Alvin submersible. Photos at left (A&B) show the activity at M-vent in 2004 when the MISO HOBO™ hi-T logger was installed. Photo C shows the HOBO™ logger (red arrow) as imaged using the TowCam digital towed deep-sea camera system during the 6NH New Horizon cruise that initially mapped the 2005-06 EPR eruption [Cowen et al., 2007]. Photo D shows the logger (red arrow) in the extinct M-vent chimney with the new lava surface only ~50 cm below the logger housing. Photo E shows the logger (red arrow) being recovered by Alvin's manipulator during the AT11-06 cruise in June 2006. Horizontal bar in each image is ~50 cm. See Figure 4 for M-vent temperature record during the 2005-2006 eruptions.



Time-series measurements (recorded at 36 minute intervals) show that M-vent exit fluid temperatures dropped dramatically from ~360°C to below 152°C within a few hours on Jan. 9, 2006 (Figure 3). This event pre-dates by ~14 days an intense pulse of microseismicity linked with one phase of the 2005-06 volcanic eruptions in this region believed to have occurred on Jan. 22, 2006 [Tolstoy et al., 2006; Dziak et al., 2009; Tan et al., 2016]. High-temperature flow at M-vent resumed on Jan. 24, 2006, finally reaching a stable temperature of ~380°C on Feb. 18, 2006, a marked shift of ~20°C above pre-eruption vent fluid temperatures [Fornari et al., 2012]. Deep-sea photo documentation of the survival of the M-vent HOBO™ logger in May 2006 and recovery of the logger in late June 2006 confirmed hydrothermal **inactivity** at M-vent. Newly erupted lava was observed ~ 0.5 m below the logger and suggests a causal link between microseismicity, vent behavior, faunal community composition, and volcanic eruption (Figure 3).

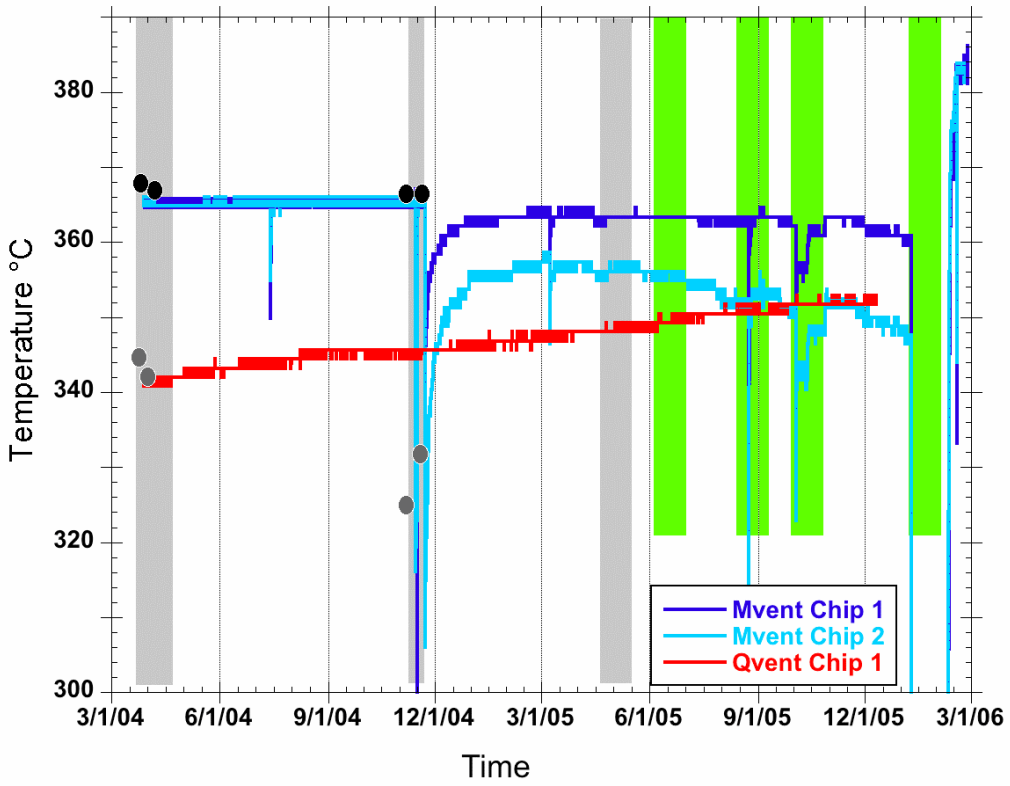


Figure 4. HOBO™ logger data recorded at ~36 min intervals for M-vent (blue lines) and Q-vent (red line) at the East Pacific Rise (see Figure 2 for locations) between 2004-2006. Gray vertical lines show periods when Alvin was diving at these vents. Green vertical bands show approximate ranges for Po-dates determined by Rubin et al., [2008] for phases of the 2005 - 2006 EPR volcanic eruptions. The steady and high vent temperatures at M through late 2004 and into early 2005 imply a stable plumbing system and hydrothermal source. The logger was disturbed by Alvin diving at the vent area in November 2004, which accounts for the brief anomaly in the record, and this may also account for the much less pronounced mid-March 2005 anomaly. After March 2005, no Alvin or other known submersible operations occurred at this site that could have disrupted the HOBO™ record. There are four, additional prominent

anomalies in the M-vent HOBO™ data, likely linked to magmatic perturbations to the hydrothermal system feeding this vent caused by the 2005-06 eruptions. Two were relatively short duration, sudden ~50°C decreases in vent temperature occurring in August and October 2005 recorded on both logger chips. The last two anomalies profoundly disrupted the M-vent HOBO™ record and are synchronous on both chips in the logger. On Jan. 9, 2006, the temperature decreases from ~350°-360°C to below 152°C, the lower threshold of the logger's measurement range. On Feb. 6, 2006 the temperature rose abruptly above 152°C reaching 376°C over a period of 7 days. The temperature response recorded by both chips was erratic for the first two days in this interval, then monotonically increases for the next 4 days and finally plateaus at ~376°C on February 1, 2006. For the next ~10 days the temperature was relatively uniform, but after February 2, 2006, it increases steadily to ~385°C. On Feb. 26 the M-vent record stops because of low battery power. When M-vent was visited in June 2006 there was no obvious hydrothermal flow.

M-vent was revisited by Sievert in January 2014. While it appeared to be inactive closer inspection revealed a small area of fluid flow emanating at the top of the structure (Figure 5). The measured temperature was 35°C, however, its chemical composition indicates that it might be a high temperature fluid that has undergone conductive cooling (relatively high methane and low sulfate) and possibly reacted below ground. Sievert et al. believed that while M-vent was not emitting high T fluid in 2014, there was still a high-T reservoir subsurface that was being tapped. When M-vent was revisited in May 2017 by Sievert, white bacterial mats & filaments were observed on top of the structure and the fluid flow appeared to be more vigorous (Figure 5, right). One hypothesis is that M-vent became reactivated post 2014.

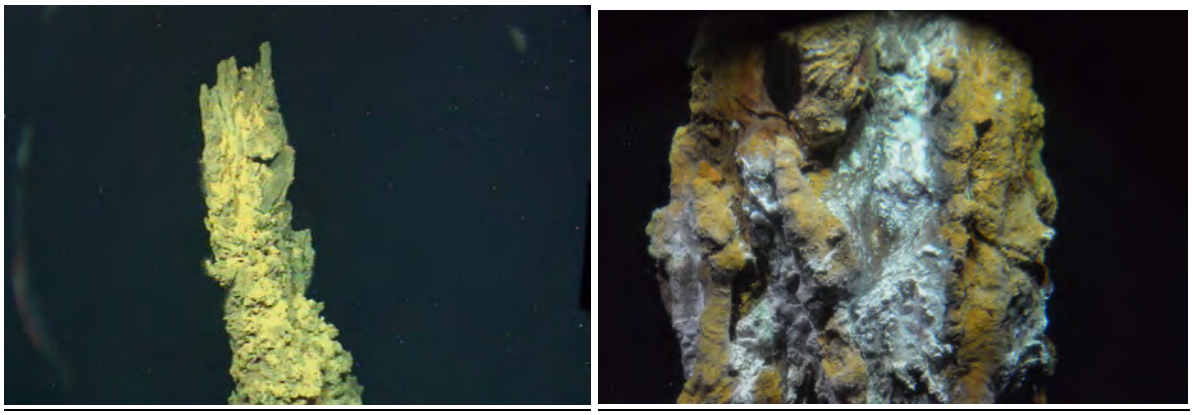


Figure 5. M-vent structure, top in 2014 from Sievert (WHOI) (left) and in 2017 (right) showing active microbial mats/filaments colonizing the chimney surface, thought to be caused by reactivation of the vent.

- **Observations at "Teddy Bear" vent** (just east of the AST at 9° 50.5'N, slightly south and east of M/Q vents – see Figure 2 for locations), made by S. Sievert (WHOI) over 3 dive programs in 2013, 2014 and most recently in 2017, suggest that in 2014 this site was characterized by diffuse-flow venting, with white staining, fuzzy coating of rocks (hence name), and smoky water. In 2014 there were no animals (see Figure 6). At the time,

Sievert believed that this site had recently become active and had not yet been colonized. This suspicion was corroborated in 2017, when they found the site colonized by Riftia with a size that would be consistent with a colonization 3 years earlier. Those investigators take this as strong evidence that the site became active shortly before their visit in Jan 2014, and that because of the spatial proximity of the site to M-vent that this could be related to subsurface reactivation of M-vent and increased/sustained sulfide-rich fluid flow.

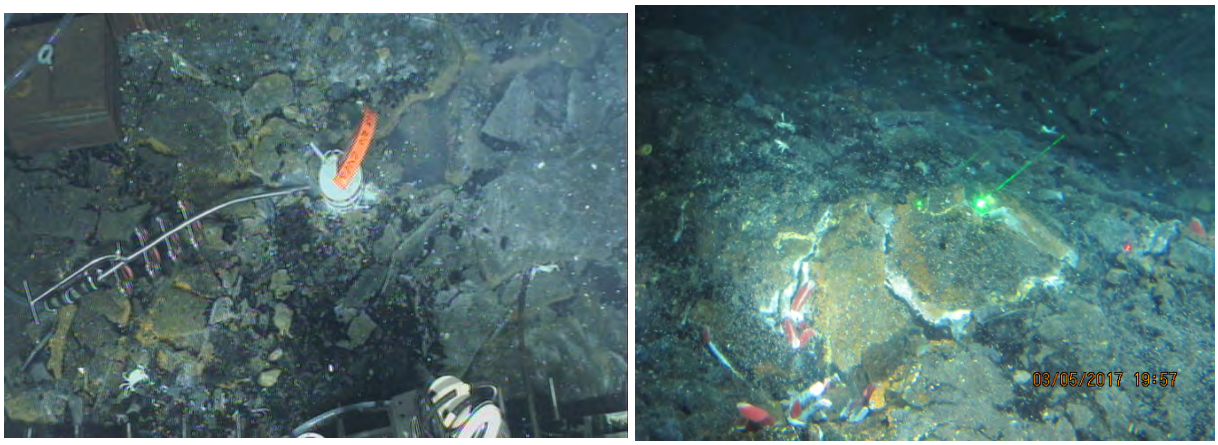


Figure 6. Teddy Bear vent (images courtesy of S. Sievert – WHOI), imaged in 2014 (left) when the site was discovered and consisted of active diffuse flow and white microbial coating on lava surfaces, and right in 2017, ~3 years later showing young riftia colonizing the diffuse flow cracks.