

# Volcanic Eruptions at East Pacific Rise Near 9°50'N

Evidence for recent volcanic eruptions along the fast spreading East Pacific Rise (EPR) crest near 9°50'N spanning about four to five months of activity was discovered in April–May 2006 as a result of studies related

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to the U.S. National Science Foundation's (NSF) Ridge2000 (R2K) program. In April, during routine recovery and redeployment of ocean-bottom seismometers (OBSs) at the EPR R2K Integrated Study Site (ISS) near 9°50'N, eight of 12 OBSs could not be recovered [Tolstoy *et al.*, 2006]. Anomalous turbidity and temperature structure in the water column along the ridge axis confirmed scientists' suspicions that the OBSs were trapped by a new lava flow.

A resurgence in magmatism recently had been postulated, based on temporal changes observed over the past few years in hydrothermal vent fluid chemistry and temperatures [Von Damm *et al.*, 2004] and increasing microseismicity [Tolstoy *et al.*, 2006]. Within a week of the initial bottom-water surveys in late April, a rapid-event-response expedition on board the research vessel (R/V) *New Horizon* was mobilized. Conductivity-temperature-depth (CTD) and optical tow-yo (tows during which a package is alternately lowered and raised) surveys, hydrocasts, and towed digital imaging surveys at the EPR axis between ~9°46'N and 9°57'N unequivocally confirmed the occurrence of recent extensive seafloor eruptions along >15 kilometers of the ridge axis and up to approximately one kilometers off axis, and they documented widespread vigorous hydrothermal venting and a notable absence of vent megafauna (Figure 1; <http://www.ridge2000.org/science/tcs/epr06activity.html>). Many of the hydrothermal vents studied over the past 15 years were disrupted.

This is the first repeat eruption documented

at the same location along the mid-ocean ridge (MOR) crest; a prior eruption occurred in 1991–1992 [e.g., Haymon *et al.*, 1993].

## Response Survey Strategy and Methods

The primary objective of the rapid-response cruise was to determine whether or not a volcanic eruption recently had taken place, and if so, to assess its extent and its hydrothermal and biological impact. Ship-board equipment included a CTD with optical and electrochemical sensors and Niskin™ water sampling bottles [e.g., Baker *et al.*, 1994] and a digital deep-sea camera with rock and water sampling capabilities (Woods Hole Oceanographic Institution TowCam [Fornari *et al.*, 2003]). These instruments were easily-mobilized and efficient tools to examine eruption effects on the water column, hydrothermal venting, and existing biological communities along the EPR axial summit trough (AST).

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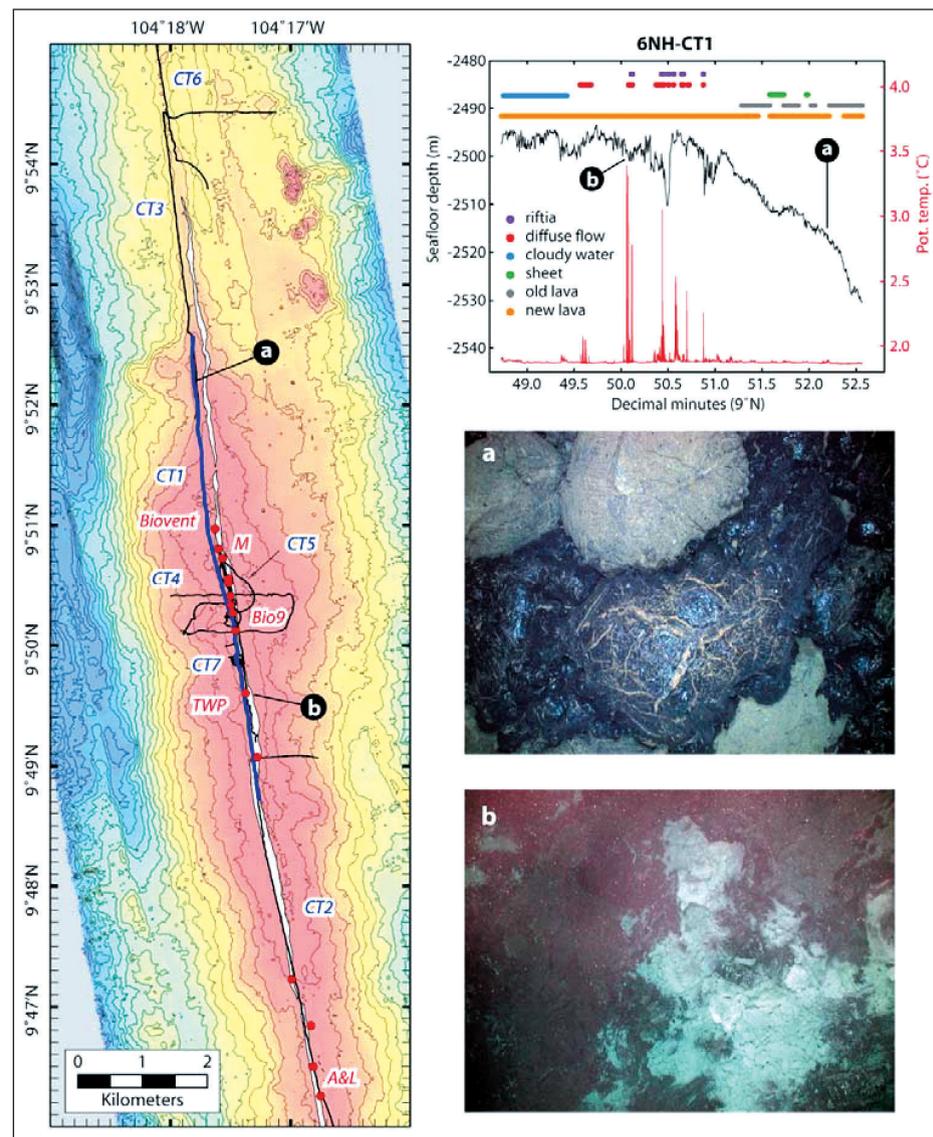


Fig. 1. (left) Location map of TowCam surveys over the new eruptions. Red circles indicate positions of old high-temperature hydrothermal vents. (top right) Near-bottom seafloor profile compiled from depth and altitude data from TowCam 1 is shown with geological and biological observations keyed to colored symbols. Potential temperature from TowCam is shown in red below the profile. TowCam photographs, keyed to their location along the track, include (middle right) new pillow to lobate lava flow overlying older sediment covered pillows and (bottom right) diffuse hydrothermal venting through recently erupted lava covered with potential microbial material.

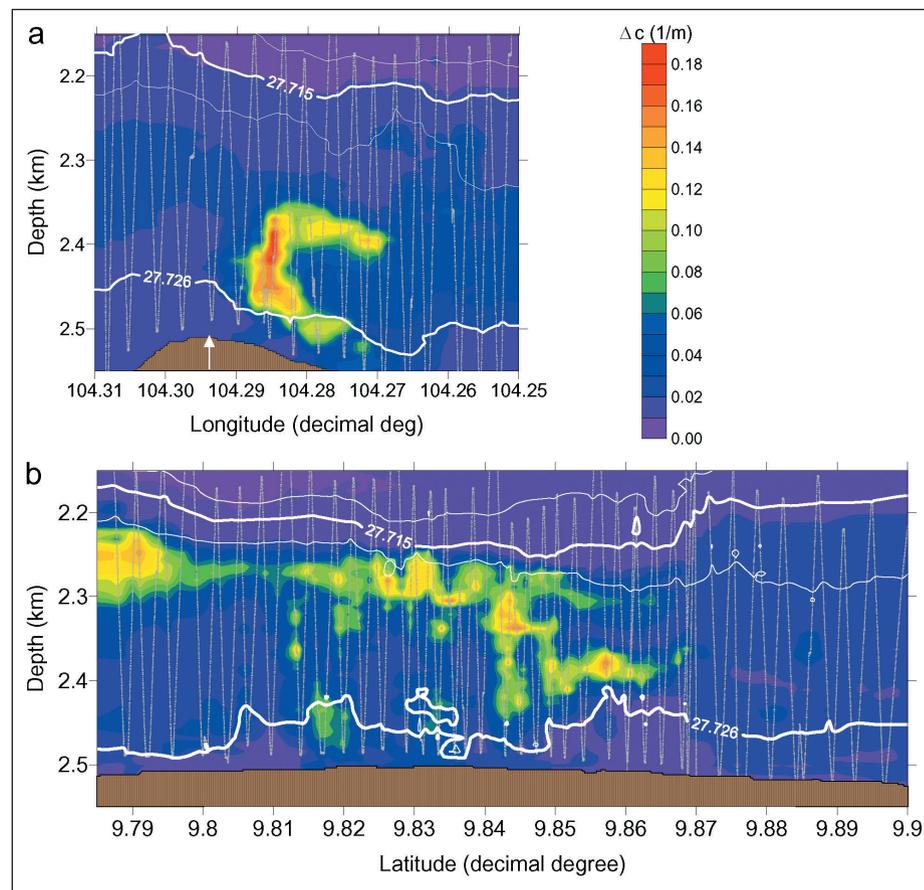


Fig. 2. Contour plots of light attenuation ( $\Delta c$ ; per meter) versus (a) depth and longitude for a cross-axis (CTD Tow 5) tow-yo and (b) depth and latitude for an along-axis tow-yo (ridge summit). Density ( $\sigma$ -theta; kilograms per cubic meter) contours (solid white curves) are superimposed over  $\Delta c$ ; the deepest-density line indicates localized areas of instability in the lower part of the water column. The dotted grey curve indicates the sawtoothed tow pattern of the instrument package (SeaBird SBE-911 CTD configured with SeaTech 347 light backscatter sensor; WetLabs CST493DR transmissometer; LISSTDeep laser in situ scattering and transmission sensor (particle size distributions); ISEA electrochemical analyzer; and a rosette of 21 ten-liter SIO-built, Niskin-style sampling bottles).

### Hydrothermal Plume Observations

During seven days on station, three tow-yos were performed along the axis between 9°46.3'N and 9°54.2'N, as well as three cross-axis tow-yos and two vertical casts (Figure 1). Along-axis tow-yos revealed particle plumes from 9°46.6'N to approximately 9°54.0'N (Figure 2a). The most intense particle plumes were centered near 9°46.6'N and 9°51.5'N and also remained strong over the 9°50'N area, site of the most intense particle plume observed in late April. Cross-axis tow-yos revealed that deep currents were advecting the plumes primarily to the east during the cruise (Figure 2b).

Pronounced density inversion layers were found throughout the deepest 250 meters of water between 9°48.5'N and 9°50.5'N (Figure 2a), consistent with vigorous hydrothermal venting but complicating the calculation of accurate temperature anomalies ( $\Delta\theta$ ), another conventional indicator of hydrothermal plume intensity [e.g., Baker et al., 1994]. Nevertheless, positive estimates of  $\Delta\theta$  of approximately 0.01°C were observed in the bottommost 250 meters over the same region of the AST, with the highest  $\Delta\theta$  (0.02 to >0.08°C) observed between 9°49.8'N and 9°50.8'N, and near 9°47.4'N. The strongest density inversions coincide with the largest  $\Delta\theta$  [Tolstoy et al., 2006]. Baker et al. [1994] found similarly low temperature anomalies in the post-1991 EPR eruption plumes, and they attributed this to hydrographic masking of  $\Delta\theta$  due to low salinity of the discharge fluids.

### Plume Chemistry

Shipboard analyses indicated abnormally high levels of methane ( $\text{CH}_4$ ) in the neutrally buoyant plumes to 350 nanomolar concentration (nM), with even higher levels in near-bottom-collected (TowCam) samples (to 937 nM), the latter possibly reflecting buoyant plumes over diffuse vents. Plume methane values are 4–100 times higher than normally found for 'stable' chronic-style plumes from hydrothermally active unsedimented ridges, and they are significantly greater than methane values (to 80 nM) measured over this portion of the EPR six months after the 1991 eruption [Mottl et al., 1995].

Stable carbon isotope values ( $\delta^{13}\text{C}$ ) for replicate gas samples collected in May 2006 averaged  $-20.34 \pm 6.87\%$  in the CTD-rosette water column samples, but were lower (averaging  $-30.25 \pm 10.34\%$ ) in near-bottom TowCam samples. Local (<2200 meter depth) background  $\delta^{13}\text{C}$  values were  $-35.9 \pm 8\%$  (for  $0.6 \pm 0.3$  nM  $\text{CH}_4$ ). The variable  $\delta^{13}\text{C}$  values in the near-bottom, high- $\text{CH}_4$  samples could indicate multiple methane source processes including microbial methanogenesis, the latter suggested by the prevalence of low-temperature venting in TowCam photographs. The more  $^{13}\text{C}$ -enriched residual methane measured in most plume samples indicates active microbial methane oxidation throughout the lower water column along the AST.

Sulfide was detected in shipboard water column analyses as well as by in situ electrochemical analyzer (200 of 4059 scans, between 9°46.98'N and 9°52.5'N). The distribution of detectable (>0.1 nM) in situ hydrogen sulfide ( $\text{H}_2\text{S}$ ) concentrations is consistent with that for the particle plumes and regions of vertical instability (Figure 2a).

### Hydrothermal Plume Microbial Diversity

Extensive expulsion of microbial biomass and products, including microorgan-

isms apparently uniquely adapted to deep, hydrothermally active subsurface environments [e.g., Summit and Baross, 1998], have been recognized with past seafloor volcanic eruptions. Terminal restriction length polymorphism analysis of 16S rRNA genes amplified from biomass samples recovered with an in situ large-volume pump revealed differences in microbial diversity between the hydrothermal plume and ambient background.

These results were confirmed by restriction analyses of full-length 16S rDNA clones where one pattern dominated plume samples (39–56% of clones) while being nearly absent in the background (4%). After analysis with a second restriction enzyme, clones with this pattern were divided into 15 different subpatterns. Further analysis is needed, but it is expected that the microbial community present in these hydrothermal plumes is dominated by one group of organisms. While the hydrothermal venting apparently influenced community diversity within the resulting hydrothermal plumes, further work is needed to identify the origin and geochemical impact of this change.

### Geological and Biological Observations From TowCam Surveys

Along-axis TowCam surveys (Figure 1) acquired nearly continuous image coverage from 9°46'N to 9°57.6'N mostly within and sometimes just outside the AST. Hydrothermally active areas were identified by an approximately 0.5°–2.0°C increase in potential temperature that frequently coincided with images of flocculent material in the water column or apparent microbial coatings on fresh lava surfaces (Figure 1).

Recently erupted lava was devoid of sediment but typically was dusted with white to brownish material (Figure 1), similar to that observed following the 1991 EPR eruption [e.g., Haymon et al., 1993]. Contacts between the new lava flow and older terrain were readily discernable in photographs (Figure 1). The new eruption covers about 15 kilometers along axis from 9°47.5'N to 9°55.7'N and between approximately one kilometer to only a few hundred meters east and west of the AST. The new lava flows (typically <1 meter thick) largely were erupted from fissures in the AST and overflowed the trough in many places, spilling out onto the EPR crestal plateau.

Further, the morphology of the new eruptions within the AST often is chaotic, consisting of sheet and hackly lava as well as flattened lobate forms suggesting high effusion rates. None of the preeruption hydrothermal vents within the AST floor in the 9°49'N–50.3'N area was directly observed, but many of the older vent sites were coincident with active venting, apparent microbial production, and in a few cases, older sulfides engulfed by new lava. In one case, a self-recording, high-temperature fluid logger was observed on the south side of M vent chimney near 9°50.7'N on the east rim of the AST (Figure 1).

TowCam images revealed hydrothermal activity from 9°46.5'N to 9°54.9'N, most concentrated between 9°49.7'N and 9°51.5'N (tens of meters of spacing between vents). To date, only diffuse venting has been photographed, but water column tow-yos indicate the presence of high-temperature venting. Extensive white mats, presumed to be microbial material, existed in all areas of active venting. Snow-blower-type venting was observed in at least three locations. No sessile faunal colonization was observed

in 'newly venting' areas. The only extant communities observed were tubeworm tubes (all apparently belonging to *Riftia pachyptila*) near 9°49.2'N and 9°50.5'N. The similarities in the biological and volcanic features observed in May 2006 relative to observations following the 1991–1992 EPR eruption [e.g., Shank et al., 1998] suggest that one or more eruptions occurred at the EPR ISS over the previous nine months.

### Importance of 'Rapid-Event Responses'

These results demonstrate that 'rapid-event response' to MOR eruptions can be quickly and efficiently mounted (i.e., in <1 week) to areas outside the northeast Pacific, and that these surveys can effectively document recent seafloor eruptions, identify transient posteruption processes, and initiate longer-term studies. The data presented provide conclusive proof that new volcanic flows have been erupted at the EPR ISS, and that the near-bottom hydrographic and hydrothermal systems as well as extensive faunal communities have been significantly affected. These studies facilitated further response efforts, primarily in the form of an Alvin/Atlantis cruise (AT15-6) that took place from 18 June to 6 July 2006, within approximately three weeks of the completion of the *New Horizon* surveys

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### Joint NSF-MARGINS and SFB574-DFG Workshop

## Workshop to Integrate Subduction Factory and Seismogenic Zone Studies in Central America Heredia, Costa Rica, June 18-22, 2007

**Convened by:** Eli Silver (esilver@pmc.ucsc.edu), Terry Plank (tplank@bu.edu), Kaj Hoernle (khoernle@ifm-geomar.de), Marino Protti (jprotti@una.ac.cr), Guillermo Alvarado (GAlvaradol@ice.go.cr), and Victor González (vgonzale@una.ac.cr)

### Applications Due: March 20, 2007

A workshop on Central America subduction studies will be held in Heredia, Costa Rica, June 18-22, 2007. This workshop, co-sponsored by MARGINS and the German SFB574-DFG, will integrate offshore and onshore studies carried out in Central America over the past 5 years. A wide array of topics will be covered, including the Seismogenic Zone (updip limit, geodetic vs. seismologic observations, silent slip events, fault zone permeability, imaging, and hydrotectonic pulsing) and the Subduction Factory (composition, age, structure, diagenetic, metasomatic and metamorphic reactions within the subduction input and processes occurring within, structure of- and output from- the forearc, volcanic arc, backarc and mantle wedge).

Participants chosen from applicants to this announcement will be provided with full or partial funding of their costs of travel, accommodation and meals. We encourage applications from those interested in this scientific endeavor, including those from outside the USA, and especially encourage applications from assistant professors, post-docs, and