EOS
EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 84 NUMBER 41
14 OCTOBER 2003
PAGES 425–440

# Deep Submergence Synergy: *Alvin* and ABE Explore the Galápagos Rift at 86°W

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For over 25 years, hydrothermal vent communities discovered at the Galápagos Rift near 86°W [e.g., *Corliss et al.*, 1979] have provided the foundation of deep-sea vent biology as their study has led to fundamental discoveries of chemoautorophy and novel symbioses in the deep sea [e.g., *Cavanaugh et al.*, 1981]. Since 1979, numerous physiological and geochemical investigations of the Rose Garden vent community [e.g., *Hessler et al.*, 1988] have been made possible through routine access to this deep sea floor site, provided by the deep submergence vehicle *Alvin*. This research revolutionized our understanding of basic biological and chemical processes in the deep ocean [e.g., *Johnson et al.*, 1988; *Edmond et al.*, 1979].

In May-June 2002, a sea floor sampling and near-bottom mapping program was conducted using R/V *Atlantis* (AT7-13), the submersible *Alvin*, and the autonomous underwater vehicle ABE (Autonomous Benthic Explorer) [*Yoerger et al.*, 1998] to explore and study hydrothermal processes along the Galápagos Spreading Center (GSC) between 86°W and 90°W (Figure 1). This 12-day expedition coincided with the 25th anniversary of the discovery of deep-sea hydrothermal vents at the Galápagos Rift (http://www.divediscover.whoi.edu; Expedition 6). It included a planned revisit of the Rose Garden vent field to conduct multidisciplinary time-series observations and sampling that would represent a quarter-century perspective at this longest-studied, active hydrothermal vent field. The fieldwork resulted in the discovery of important geological, hydrothermal, and biological changes that have occurred at the Rose Garden site. During the first few *Alvin* dives of the cruise, it was discovered that the well-developed faunal communities last documented 13 years ago at Rose Garden were apparently buried by fresh basaltic sheet flows. Notable was the absence of 14 sea floor markers used for past experiments and 7 stacks of *Alvin* dive weights observed on dive 2224.

On the first *Alvin* dive (3788), a nascent, low-temperature hydrothermal vent field (named Rosebud) was discovered at 2470 m depth, which included an array of young vent animal assemblages colonizing cracks within a fresh, glassy basaltic sheet flow located ~300 m northwest of the last known position of the Rose Garden site

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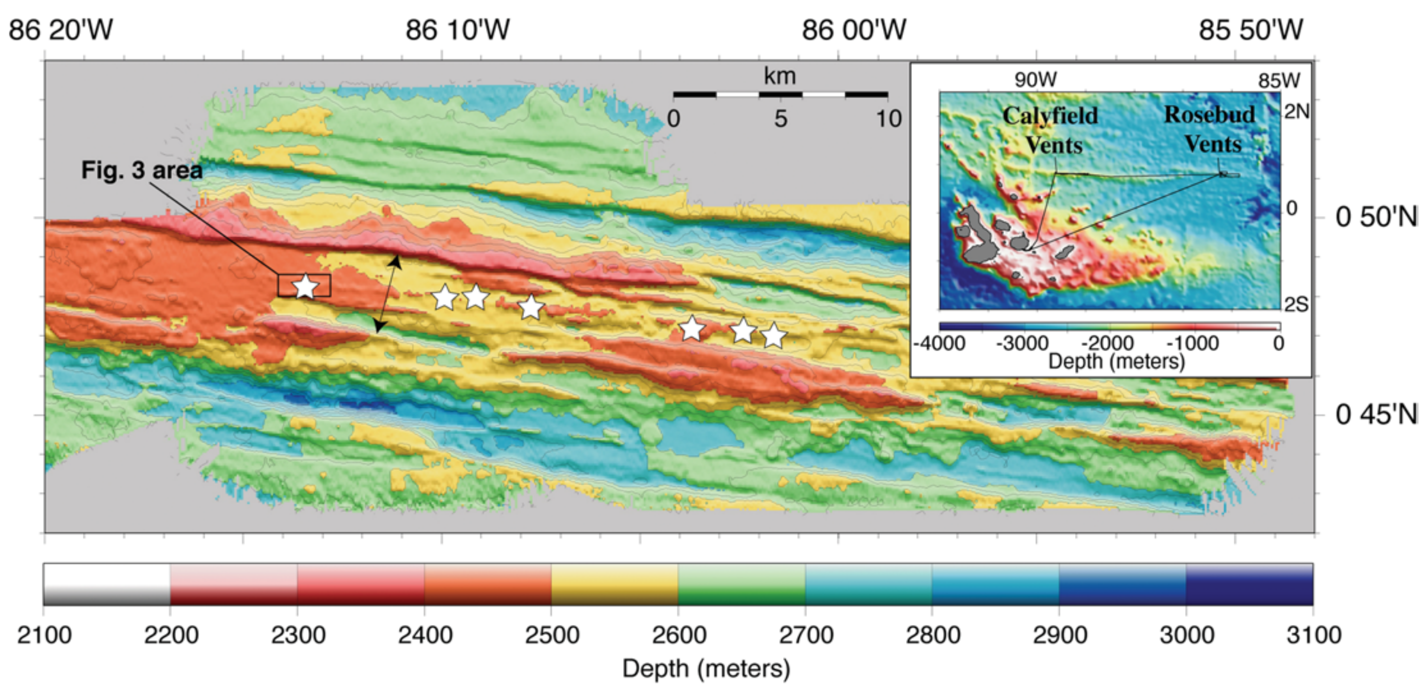


*Fig. 1. Shaded relief multi-beam bathymetric map of the Galápagos Spreading Center near 86°W from data collected on AT7-13. White stars show locations of historic vent sites reported by* Ballard et al. *[1982] and* Hessler et al. *[1988]. Black rectangle shows area of maps shown in Figure 3; white star in rectangle is Rose Garden position. Inset shows location of vent sites discovered during the cruise with respect to the Galápagos Islands (in gray) along ship track (in black). Line with arrows shows the width of the rift valley in the study area.*


*Fig. 2. (a) Three galatheid crabs resting on folds in the new sheet flow surface at the Rosebud vent site. Small pink dots are anemones that have abundantly colonized cracks in the basalt. Distance across image ~50 cm. (b)* Riftia pachyptila *tubeworms (many < 3 cm length) are growing in cracks in the sheet flow surface. Small mussels are also visible growing in cracks on the surface of the flow extending away from one of the main tubeworm assemblages. Brachyuran crab (top) and galatheid crab (bottom) feeding among tubeworms and mussels. Small pink dots are anemones. Distance across image ~30 cm. (David Metz of Canon, Inc.-USA and George Moss are gratefully acknowledged for loan of a Canon EOS 1D digital camera system used in* Alvin *to take these photographs).*

(Figure 2). Photo-mosaics generated from *Alvin* down-looking digital imagery and detailed imaging surveys of the ~60 m x 50 m Rosebud vent field revealed four major venting areas containing vestimentiferan tube worms (most < 6 cm length), linear rows of bathymodiolid mussels (average ~1 cm length) growing along cracks in the sheet lava surface (Figure 2), and adjacent carpets of amphianthid anemones (ca. 50 individuals/m$^2$).

Vesicomyid clams (ca. 10 individuals, <3 cm) were observed along cracks in the central portion of the sheet flow. The faunal communities were developing in fluids exhibiting some of the highest temperatures (24°C) yet measured at the Galápagos Rift. $H_2S$ concentrations at Rosebud were 10–40 micromol/kg, comparable to levels measured in 1977 at the Rose Garden field [*Johnson et al.*, 1998]. Bacterial and archaeal DNA phylotypes (dominated by εProteobacteria) from Rosebud were found to be closely related to those previously reported from Axial Volcano, Guaymas Basin, and the Mid-Atlantic Ridge. Sampling of the Rosebud communities using *Alvin* revealed that they contained less than one-third of the invertebrate species known from Rose Garden when last sampled 13 years ago. The Rosebud vent animal assemblage is considered to be in the early stages of community development based on previous patterns seen at the Galápagos Rift and East Pacific Rise [*Hessler et al.*, 1988; *Shank et al.*, 1998].

### *Optimizing Direct Observations and Sampling*

To confirm these unexpected findings, it was realized that a full characterization of the sea floor within the rift valley was required. The investigative strategy for ABE and *Alvin* was directed toward ensuring that all potential sites of hydrothermal venting in the rift valley within the 86°W region were identified and investigated visually using *Alvin*. The use of ABE each night to conduct high-resolution, near-bottom mapping of the water column and sea floor was critical for directing *Alvin* observations and sampling during the following day. In this manner, it was possible to rapidly establish the location of all actively venting sites within a ~1 km x 2 km area of the rift valley, place them in a geological context, and verify that no active venting was present at the location of the historic Rose Garden site (Figure 3).

ABE mapped the sea floor within the rift valley and collected conductivity/temperature/depth (CTD) data along track lines spaced ~60 m apart, from 40 m altitude at a speed of 1.5 knots (Figure 3). These parameters optimized the bathymetric and geophysical data collection while still providing good coverage for near-bottom temperature anomalies caused by diffuse flow venting. ABE acquired 1-m vertical and 5-m horizontal resolution bathymetry using a 675 kHz mechanically scanning altimeter [*Yoerger et al.*, 1998], and it also collected near-bottom magnetic field data using a three-axis fluxgate magnetometer [*Tivey and Johnson*, 2002].

Bottom water properties were measured using a Seabird SBE3 temperature sensor, SBE4 conductivity sensor, and an optical backscatter sensor for mapping and locating hydrothermal plumes. The ABE-generated maps were supplemented by CTD Tow-Yo data from the surface ship.

This activity, which used the ship's tools in a highly effective manner, provided further context for the physical structure of the water column and allowed samples to be collected, thereby confirming the chemical anomalies. Preliminary interpretation of the near-bottom magnetic field data, based on the computed magnetization map over the rift valley axis, shows a distinct magnetization low 'bulls-eye' beneath the historic location of the Rose Garden. This suggests that while no visible evidence of the venting currently exists there, a remnant magnetic 'scar' is present in the shallow crust caused by alteration of the magnetic minerals in the basalt due to past hydrothermal activity [*Tivey and Johnson*, 2002].

Typically, ABE was recovered by 0715 hours local time, and micro-bathymetry and temperature anomaly maps (e.g., Figure 3) were quickly generated, compiled with previously collected data, and used during each *Alvin* dive. Every temperature anomaly, including one as low as 20 millidegrees, was visited by *Alvin*, and each revealed a sea floor source of active diffuse venting. Detection of extremely weak plume

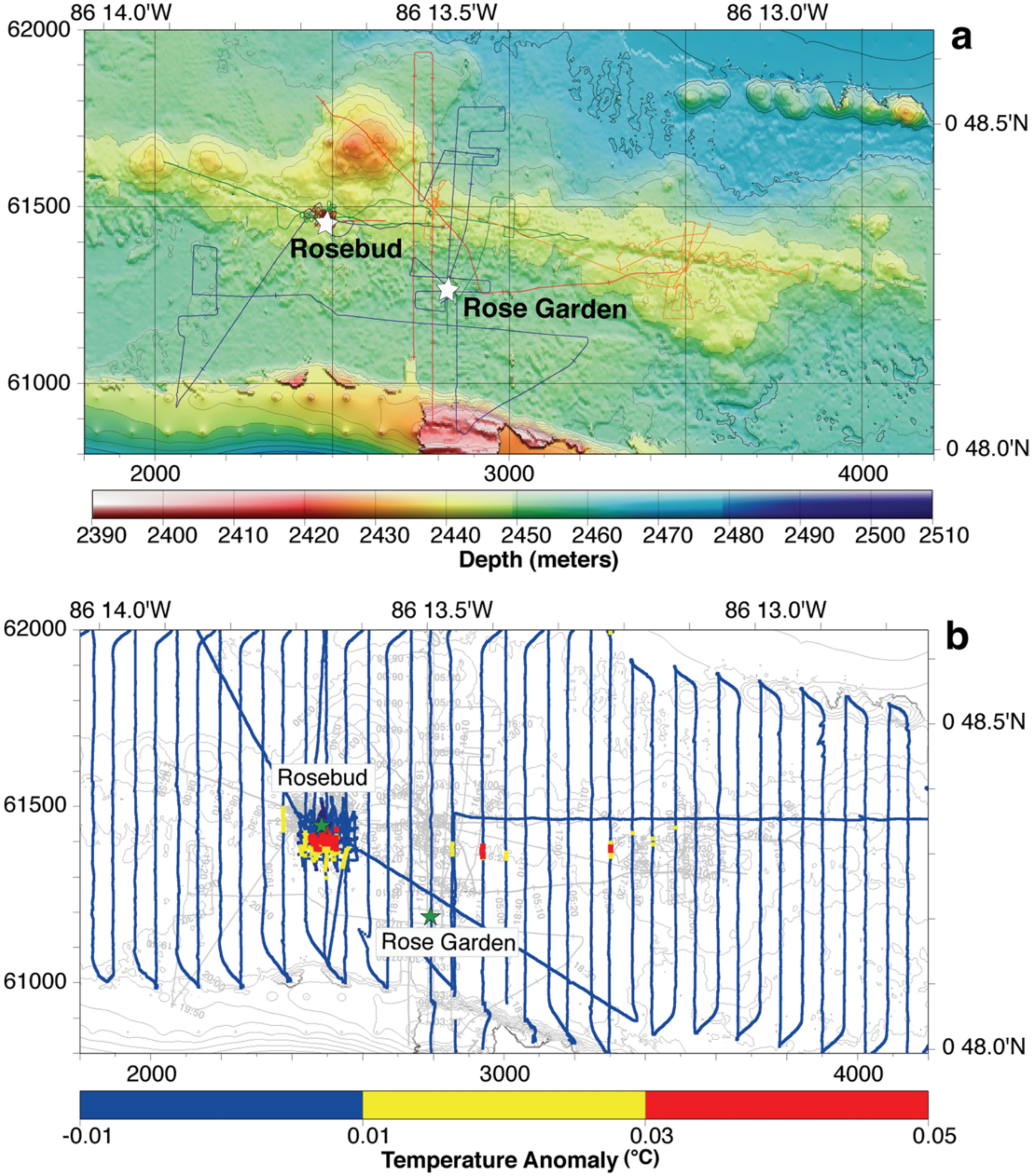


*Fig. 3. (a) Micro-bathymetry derived from ABE surveys using the Imagenex 675 kHz scanning altimeter and a Paroscientific depth sensor. Data provide 5-m horizontal- and 1-m vertical-resolution. Contour interval 5 m. Dark blue line is the track of* Alvin *dive 3788; dark green = dive 3789; dark red = dive 3790; orange = dive 3791.* Alvin *navigation represents bottom-lock Doppler 1Hz position data integrated with long-baseline navigation positions (courtesy of J. Kinsley and L. Whitcomb, Johns Hopkins University, see http://robotics.me.jhu.edu/~llw/dvlnav). Red lines indicate the path of the camera sled across the sea floor; green lines indicate CTD Tow-Yo's. The location of Rosebud vent site and historic position of inactive Rose Garden vent site are shown as white stars. Bottom and left grid labels are in meters; (b) Temperature anomaly map derived from ABE's CTD data. ABE's track lines were primarily oriented N-S and most show no anomaly (blue color). The co-located cluster of yellow and red points indicate diffuse flow venting associated with the nascent Rosebud vent site. Several additional sites of weak venting were discovered along the WNW-trending eruptive fissure present along the axis of the axial high (see Figure 3a). These sites were mapped using ABE, and observed and sampled using* Alvin. *Black lines show ABE bathymetric contours and gray lines show coverage by* Alvin *and towed camera and CTD Tow-Yo's shown in Figure 3a. Bottom and left grid labels are in meters.*

signals observed by ABE on multiple, adjacent 60 m-spaced track lines provided confidence that no active sources of venting were missed (Figure 3b). The ability to detect and characterize such small plumes was facilitated by the simplicity of the hydrographic setting at 86°W, as confirmed by CTD casts [*Yoerger et al.*, 2002].

By comparison, during later dives on this cruise to the GSC near 90°W (Figure 1)—where the ridge crest is not rifted and is much shallower (~1700 m depth)—the presence of variable tidal currents over the rough crestal topography hindered ABE from discerning small hydrothermal plumes. The rapid and comprehensive characterization of hydrothermal activity at the 86°W site over such a large region of sea floor surrounding Rosebud (ABE covered a ~3 $km^2$ area; *Alvin* traverses totaled 12.5 km) would not have been possible by either vehicle alone in the allotted time.

It is important to place our investigative strategy in a historical context. The early discoveries of hydrothermal venting at the Galápagos Rift were made by surveys that employed a variety of shipboard and near-bottom instrumentation (e.g., heat flow and CTD surveys, bathymetric mapping, and DeepTow and ANGUS imaging) [e.g., *Lonsdale et al.*, 1977; *Weiss et al.*, 1977; *Ballard et al.*, 1979]. For example, previous mapping using DeepTow [*Lonsdale et al.*, 1977] and subsequent near-bottom temperature measurements and imaging by the ANGUS towed camera system approximately one month prior to the 1977 *Alvin* diving provided scientists with targets to explore for hydrothermal vents at the Galápagos Rift near 86°W [*Ballard et al.*, 1982]. Most of these nested surveys, however, were done in sequential expeditions often separated by months to years. Our complementary use of ABE and *Alvin* on the same expedition greatly benefited scientific productivity. This ensured that we obtained a comprehensive spatial perspective of all the sea floor sources of hydrothermal effluent within the rift valley. In addition, we were able to take advantage of ABE-generated, meter-scale bathymetry and water-column anomaly mapping to better define *Alvin*'s dive plan on a daily basis. The significant scientific and operational results of this cruise underscore the paradigm shift that has taken place in recent years, in terms of how different deep submergence vehicle systems are synergistically utilized during the same cruise to optimize data collection and rapidly address fundamental scientific questions in the deep ocean and at the sea floor [e.g., *Sinton et al.*, 2002; *Cormier et al.*, 2003; *Schouten et a*l., 2002; *Embley et al.*, 2002; *Yoerger et al.*, 2002].

The recent application of ABE's various capabilities, in combination with ROV *Jason2* or *Alvin*, or as part of other mapping and sampling programs include: (1) detailed mapping and imaging surveys at the East Pacific Rise near 9° 26'–50'N in 2001; (2) high-resolution mapping of the Explorer Ridge in 2002; and (3) mapping and imaging of the Lost City vent site on the Mid-Atlantic Ridge and the New England Seamounts in 2003. Next year, several ABE programs will include exploratory imaging surveys for the first South Atlantic vent communities and initial hydrothermal characterization of the Lau Basin Integrated Study Site in 2004 (as part of the RIDGE 2000 program), in conjunction with ROV *Jason2* and DSL-120A side-scan sonar surveys. The cruises to the South Atlantic and Western Pacific will use the various vehicle systems to determine the precise location of active venting at the study sites, and then assess the distribution, abundance, and faunal composition related to hydrothermal activity and geological features using down-looking imaging surveys, and detailed bathymetric and water properties mapping. ABE surveys will provide essential data to characterize the hydrothermal systems at high resolution and to guide the submersible-based sampling programs. Planning for future deep submergence vehicle facilities should recognize the important synergies that exist between autonomous vehicles like ABE, human occupied vehicles like *Alvin*, and remotely operated vehicles.

### Acknowledgments

We thank the officers and crew of R/V *Atlantis*, *Alvin*, and the ABE Operations Group, and the shore-based personnel of the National Deep Submergence Facility at the Woods Hole Oceanographic Institution (WHOI) for their expertise and dedication in helping us acquire these data. Funding was provided by NOAA's Ocean Exploration Program, The U. S. National Science Foundation, and WHOI through the Vetlesen and Richards Foundation Grants (DJF and TS) and the W. Van Alan Clark. Sr., Senior Scientist Chair at WHOI (DJF).

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