Exploration of Hydrothermal Vents Along the Galápagos Spreading Center

By Nicole A. Raineault, Robert D. Ballard, Larry Mayer, Charles R. Fisher, Steven Carey, Leigh Marsh, Renato Kane, Suna Tüzün, Timothy M. Shank, and Clara Smart

Scientists aboard E/V *Nautilus* explored the Galápagos Spreading Center (GSC) to revisit known, and discover unknown, hydrothermal vents on cruises NA062 and NA063. The history of these seminal sites spans nearly 40 years and includes the location where hydrothermal vents and chemosynthetic ecosystems were first discovered in 1977 (Corliss et al., 1979). The cruise objectives were to conduct visual reconnaissance transects on a segment of the GSC between the westernmost known vent site, Rosebud (Shank et al., 2003), and the easternmost known vent site, Tempus Fugit (Shank et al., 2012); to determine geological and apparent biological changes at these sites; to explore the area for unknown sites of active venting; and to collect fauna not previously reported from this region (Figure 1). Another goal was to visit the Iguanas black smoker vents, located on a fault offset from the 86°W sites, to compare initial observations from 2006 (Haymon et al., 2008) with current conditions and to collect the first samples of the chimneys and vent macrofauna if any were found (Figure 1).

The Galápagos Rift is an east-west trending spreading center in the eastern equatorial Pacific. Here, the Cocos and Nazca tectonic plates are moving apart at 5–6 cm per year, an intermediate rate among the global mid-ocean ridge system (Ballard et al., 1982). The GSC's 2–4 km wide rift valley is composed of sheet flows and pillow basalt ridges, with sparse to no sediment cover indicating there has been recent volcanic activity. This rift valley was the target of *Nautilus* multibeam mapping surveys and seven ROV dives in June and July 2015.

To cover a large area, the first dive used *Argus* as a towed camera sled starting west of the East of Eden hydrothermal site. Along the 17 km westward transect, we encountered alternating expanses of fresh, glassy pillow basalts and older, sedimented pillow basalts and lava lakes. Cloudy water, clam shells, serpulid worms, and peripheral vent fauna were observed near the East of Eden 2 and 3 sites, indicating that parts of this area remained active. Miniature autonomous plume recorders (MAPRs) placed on *Argus*' frame to measure temperature, eH, and backscatter anomalies detected a spike in seawater temperature at the active sites; however, no large point-source venting or extensive vent communities were identified in this area.

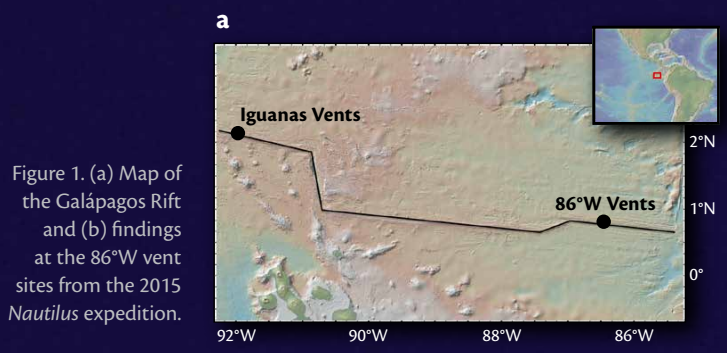
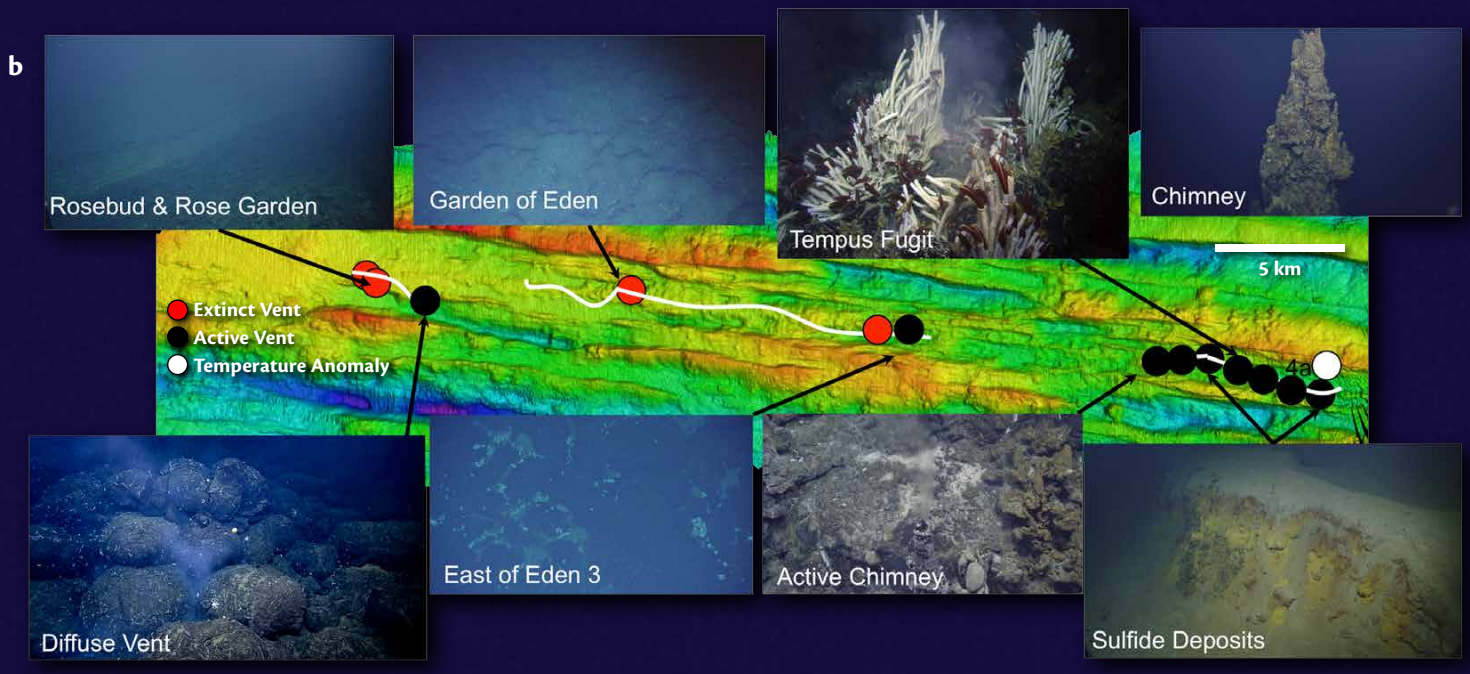


Figure 1. (a) Map of the Galápagos Rift and (b) findings at the 86°W vent sites from the 2015 *Nautilus* expedition.



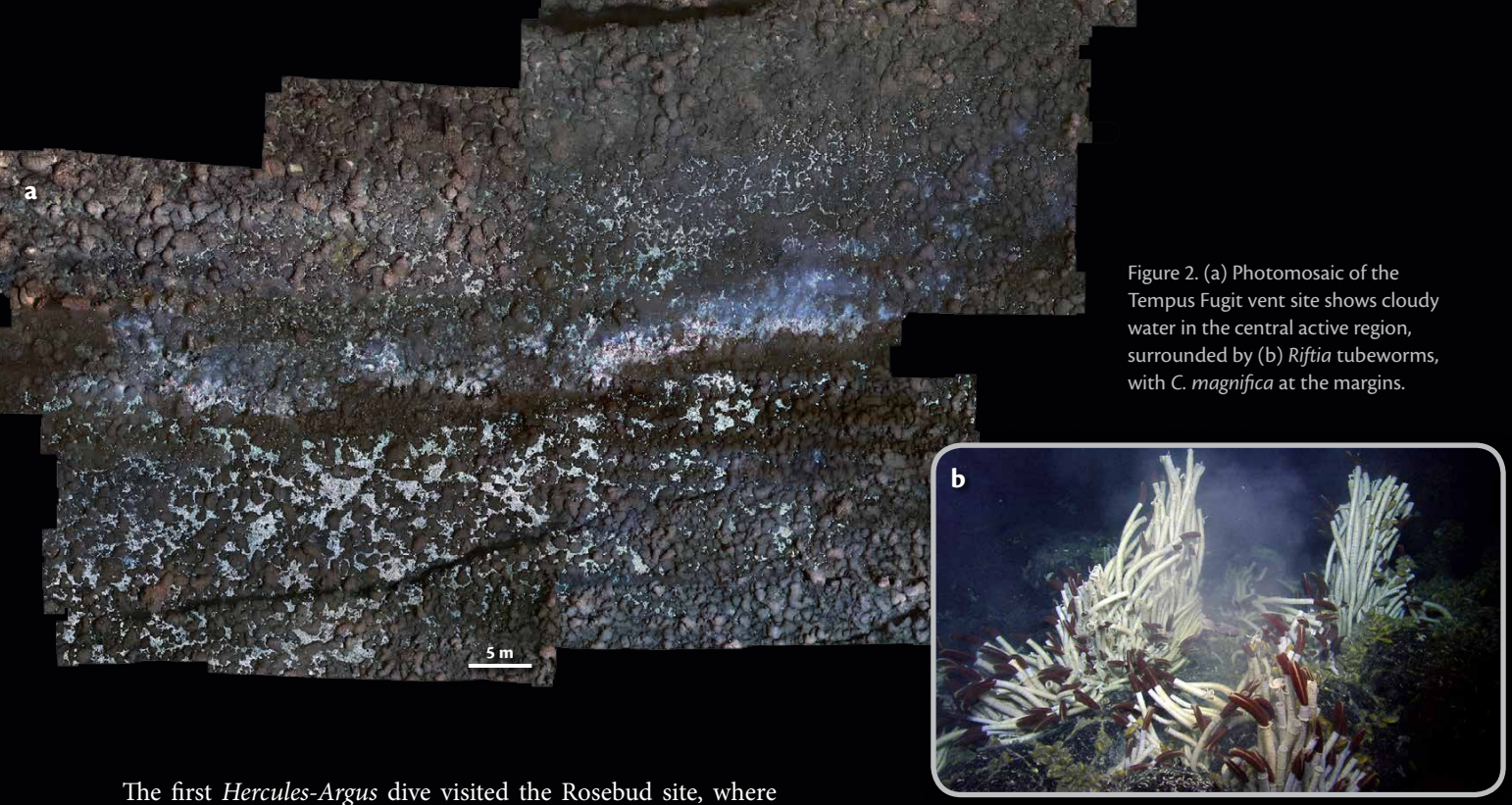


Figure 2. (a) Photomosaic of the Tempus Fugit vent site shows cloudy water in the central active region, surrounded by (b) *Riftia* tubeworms, with *C. magnifica* at the margins.

The first *Hercules-Argus* dive visited the Rosebud site, where in 2002 scientists discovered a nascent vent community containing *Riftia pachyptila* tubeworms (Shank et al., 2003). With help from scientists ashore, the shipboard scientists explored the area, looking for previously observed sheet flows or white markers left by past expeditions. Instead of active hydrothermal venting, this site appeared to be covered by fresh basalt. Several lava lakes with collapse structures and pillars were also observed in the area. Neither markers left previously nor vent fauna documented in 2001 were observed, suggesting they were buried by more recent lava flows. The Rosebud vent was in the same area as the Rose Garden site, one of the original vent sites discovered in 1977. In this same region in 2015, we observed increased sediment cover and a large lava lake. Working .5 km to the east of the Rosebud site we observed cloudy near-bottom water and serpulid worms on the seafloor. The ROVs tracked a deep, narrow fissure, but ended the dive before finding the source of the cloudy water.

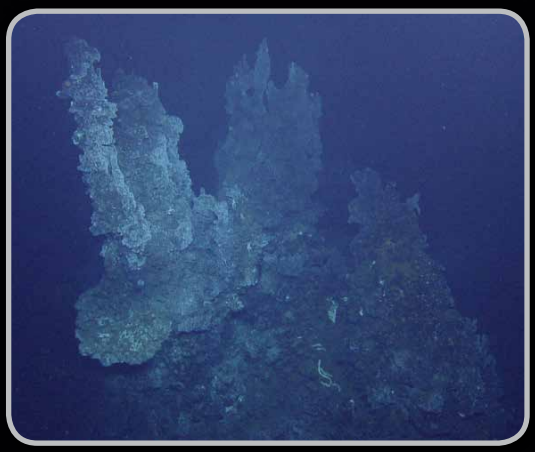


Figure 3. Chimney structures on the eastern segment of the Galápagos Rift show that high-temperature venting once occurred in this area.

The next dive was at the Tempus Fugit vent, discovered in 2010 by *Okeanos Explorer* (Shank et al., 2012). When first observed, scientists estimated that periods of venting activity and inactivity were more than 20 years old based on large dead *Calyptogena magnifica* clam assemblages present at the periphery of the vent field (Karson et al., 2015). However, small tubeworms (*Riftia pachyptila*) and mussels (*Bathymodious thermophilus*) were also found, indicating recent and active colonization (Shank et al., 2012). This dichotomy of old and new led to the vent being named Tempus Fugit or "time flies." During additional ROV dives, scientists aboard *Nautilus* found abundant live *B. thermophilus* mussels and large living *C. magnifica* clams surrounded by hundreds of square meters of disarticulated *C. magnifica* shells, confirming that this site has been active for many years, but alterations in subsurface plumbing have resulted in localized changes in the spatial patterns of diffuse venting. A photomosaic of the area is helping scientists analyze the distribution of fauna around the vent (Figure 2a). The map covered the entire venting area (100 × 150 m), which remains one of the largest low-temperature vent fields known along the GSC.

What may prove to be the most geologically significant discovery, an extinct sulfide chimney (Figure 3) was found and then sampled during a visual survey of the rift east of Tempus Fugit in the area of a water column anomaly (site 4a in Figure 1b). This area had not been visually investigated by *Okeanos Explorer* in 2010. Sediment covering the volcanic substrate suggests this area had been inactive for some time. During an 8 km transit, several chimneys and sulfide deposits ranging from .5 m to over 1.5 m tall were observed. White and blue bacterial mats were seen blanketing the seafloor over diffuse flow vents near the chimney complexes. The base of a large chimney structure venting white fluids as well as adjacent chemically stained sediments supported vent-endemic

fauna, including the Pompeii worm (*Alvinella pompejana*) and other polychaete worms, along with pycnogonids, rattail fish, and galatheid crabs. Unfortunately, the ROV's manipulator arm was inoperative so we were unable to sample this fauna. However, this discovery provided the first evidence that the eastern segment of the GSC may have contained high-temperature black smoker vents. It was hypothesized that the white smokers may be black smokers in waning stages of activity.

Previously, the only known black smoker vents on the GSC were located about 660 km west of the site of our first dives and were offset from the others vents. The Iguanas vents were discovered by remote chemical sensing of the water column and photographed by camera sled in 2006. They were visited by the human-occupied *Alvin* submersible and mapped by an autonomous underwater vehicle in 2011, but had not been sampled or examined extensively using an ROV prior to our 2015 exploration. This vent field contains the tallest and largest number of active chimneys and the tallest, most vigorous smokers observed anywhere along the GSC (Haymon et al., 2008). The Iguanas chimneys produce dense black smoke and sit directly on pillow lavas, and the chimney bases are surrounded by white bacterial mats. There are at least three active chimney clusters pumping out 200°C fluids within an area extending approximately 100 m along strike. Some chimneys are up to 13 m tall and topped by multiple active spires (Figure 4). The *Hercules-Argus* ROVs surveyed several of these chimneys. Previous studies had not documented any of the classic chimney fauna found along the East Pacific Rise, but the *Nautilus* dives observed and collected communities associated with the iconic hydrothermal vent chimney polychaete *A. pompejana* near shimmering water venting from beehive-like structures. Away from hydrothermally active sources, carnivorous sponges, black corals, and serpulid worms were also observed between chimneys. These observations and collections are adding considerably to our knowledge of the biogeography of vent fauna in the East Pacific Rise-Galápagos Spreading Center region. Additional work to create a photomosaic of a black smoker, measure the black smoker flow rates, and use low-light cameras to detect bioluminescence was also conducted at this site. Structured laser light surveys over an area of diffuse flow among pillow lavas covered with gray-blue bacteria will be used to estimate flow rates.

These *Nautilus* cruises will help to better understand the history of the Galápagos hydrothermal vents and the relationship of the communities there to other vent communities around the world. There are large differences between fauna reported from the nearby East Pacific Rise and those previously known from the GSC. More than 40% of species endemic to the East Pacific Rise are absent from the Galápagos Rift (Shank et al., 2014), although scientists hypothesize that this may be partly due to our previous lack of collections from high-temperature chimneys along the GSC (Shank et al., 2014). We also obtained samples representative of a variety of different habitats, including mussel beds, mixed mussel and clam beds, and *R. pachyptila* tubeworm clumps. These collections appear to contain several additional new species, and they complement previous collections from this region. Samples from these cruises have been distributed to experts around the world to determine how many new species were found and how they are related to East Pacific Rise species. Compilation of these data will inevitably result in a new understanding of the biogeographic connectivity between the GSC and the East Pacific Rise. The geological activity of the GSC can also now be re-examined. We observed that new seafloor has been created over the last 10+ years at the western end of the rift. Newly discovered inactive chimneys on the eastern end of the rift suggest that this area once was the location of high-temperature venting, a process previously unknown on this segment of the GSC. Our results may change our understanding of rare mineral deposits in the area. Given the increased interests of mining companies in polymetallic sulfide deposits along mid-ocean ridges and the possible impact such activities might have on vent communities, it is important to point out the small amount of time it took to discover and sample major deposits associated with inactive sites. Geologists are working to determine the potential volume of sulfides deposited at now inactive areas of the GSC.

Figure 4. Active black smoker in the Iguanas vent field on the western segment of the Galápagos Spreading Center.