6-3-1997

Researchers Rapidly Respond to Submarine Activity at Loihi Volcano, Hawaii

F. K. Duennenbier

N. C. Becker

Jacqueline Caplan-Auerbach
Western Washington University, jackie.caplan-auerbach@wwu.edu

D. A. Clague

J. Cowen

See next page for additional authors

Recommended Citation

Duennenbier, F. K.; Becker, N. C.; Caplan-Auerbach, Jacqueline; Clague, D. A.; Cowen, J.; Cremer, M.; Garcia, M.; Goff, F.; Malahoff, A.; McMurtry, G. M.; Midson, B. P.; Moyer, Craig L.; Norman, N.; Okubo, P.; Resing, J. A.; Rhodes, J. M.; Rubin, K.; Sansone, F. J.; Smith, J. R.; Spencer, K.; Wen, X.; and Wheat, C. G., "Researchers Rapidly Respond to Submarine Activity at Loihi Volcano, Hawaii" (1997). *Geology Faculty Publications*. 52.
https://cedar.wwu.edu/geology_facpubs/52

Authors
F. K. Duennenbier, N. C. Becker, Jacqueline Caplan-Auerbach, D. A. Clague, J. Cowen, M. Cremer, M. Garcia, F. Goff, A. Malahoff, G. M. McMurtry, B. P. Midson, Craig L. Moyer, N. Norman, P. Okubo, J. A. Resing, J. M. Rhodes, K. Rubin, F. J. Sansone, J. R. Smith, K. Spencer, X. Wen, and C. G. Wheat

EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

EOS

VOLUME 78 NUMBER 22
JUNE 3, 1997
PAGES 229–237

Researchers Rapidly Respond to Submarine Activity at Loihi Volcano, Hawaii

The 1996 Loihi Science Team

PAGES 229, 232–233

The largest swarm of earthquakes ever observed at a Hawaiian volcano occurred at Loihi Seamount during July and early August 1996. The earthquake activity formed a large summit pit crater similar to those observed at Kilauea, and hydrothermal activity led to the formation of intense hydrothermal plumes in the ocean surrounding the summit.

To investigate this event, the Rapid Response Cruise (RRC) was dispatched to Loihi in early August and two previously planned LONO cruises (named for a Hawaiian warrior god) sailed in September and October on the R/V *Kaimikai-O-Kanaloa*. Calm weather and a newly refurbished ship provided excellent opportunities for documenting the volcanic, hydrothermal plume, vent, and biological activities associated with the earthquake swarm.

The Loihi rapid response cruises and earthquake records provided a wealth of data that, for the first time, documented the submarine eruption and pit crater formation of a hotspot volcano. Researchers conducted a total of 15 PISCES V submersible dives, 41 water sampling operations, and 455 km of swath bathymetry surveys, and deployed 40 sonobuoys and one ocean bottom seismometer (OBS). Glassy rocks were recovered from a 1996 eruption.

Earthquakes and Noise

Between July 16 and August 9, 1996, over 4000 Loihi earthquakes were detected by the seismic network of the U. S. Geological Survey's Hawaiian Volcano Observatory (HVO). The initial phase of activity, consisting of 72 located earthquakes, continued for two days. After 30 hours of quiescence, activity resumed and continued at a higher rate, averaging over 88 located events per day for the next 10 days before slowing.

Preliminary locations calculated using the HVO seismic network data placed the majority of events between depths of 10 and 14 km shallowing seaward. However, P wave arrivals at an OBS deployed on Loihi summit during the third week of the swarm arrive about two seconds early, suggesting that the velocity model used for the island of Hawaii is inappropriate beneath Loihi and that initial locations are inaccurate. Using HVO's preferred velocity model under Hawaii and lower velocities at shallow depths under Loihi, reasonable hypocentral locations are obtained between 7 and 8 km depth (Figure 1). Despite the obvious topographic modifications of the summit, few shallow earthquakes (between 0 and 5 km) were located.

Sonobuoys dropped from the K-O-K to listen for earthquakes and eruption sounds detected bangs, pops, and grinding noises with frequencies from tens to several hundred hertz at three distinct locations on the northeast side of the summit, moving from south to north with time. An active area just north of East Pit was detected during the RRC, and two areas were located during the first LONO, one on the east flank at a depth of about 1600 m and one just north of the summit. Attention to other priorities precluded detailed surveys of these sites, but turbid water was observed drifting in from these areas during submersible dives.

Structure

Swath bathymetry surveys documented the bathymetric changes at Loihi summit (Figure 2) associated with the seismic swarm.

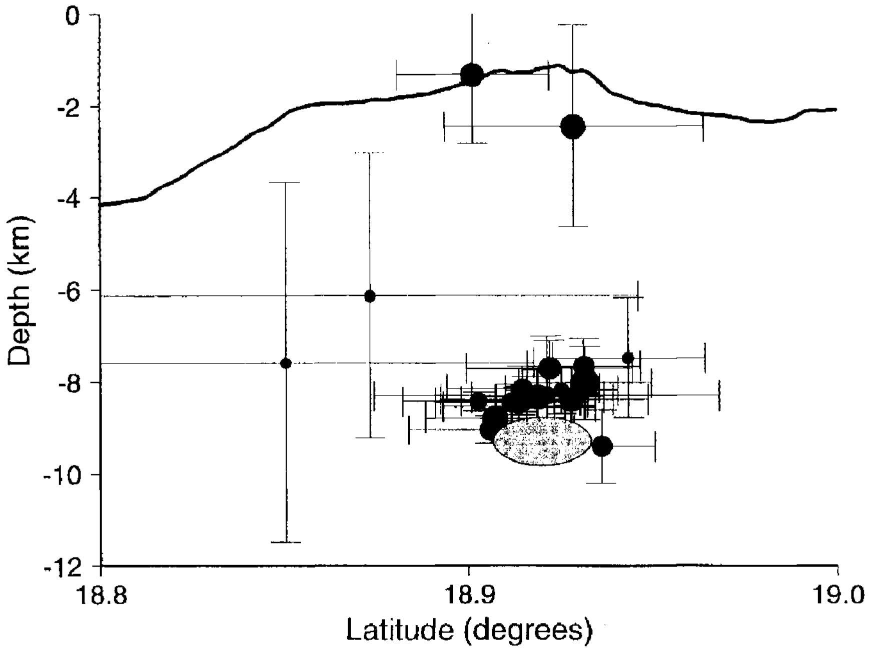

Fig. 1. Earthquake hypocenter cross-section at Loihi located using data from the Hawaiian Volcano Observatory and one ocean bottom seismometer at Loihi during August 1996. Circle size is proportional to relative magnitude. The oval at about 8 km depth indicates the possible location of a magma chamber consistent with petrological data.

For more information, contact Fred K. Duennebier, Dept. of Geology and Geophysics, School of Ocean and Earth Sciences and Technology, University of Hawaii, Honolulu, HI 96822.

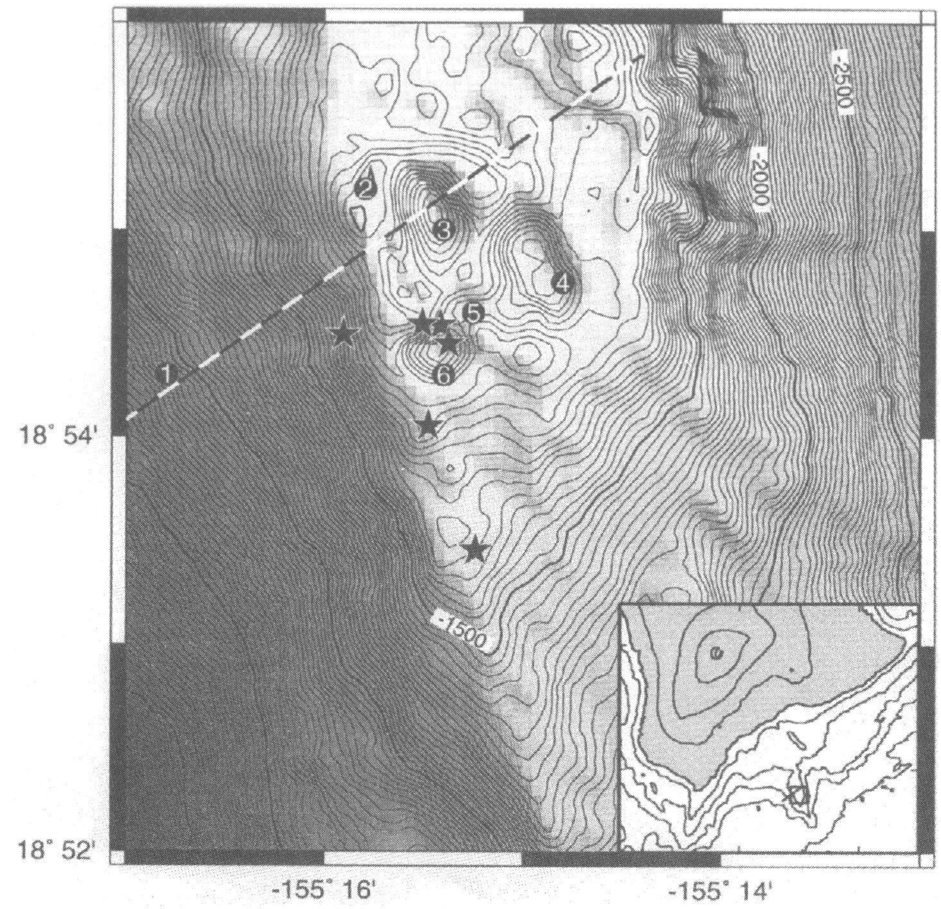

Fig. 2. Summit map obtained from K-O-K bathymetry taken during the LONO cruises. Stars identify vent sites and numbers identify the following features: 1) Tow-Yo track (Figure 4); 2) Pisces Peak (OBS station); 3) West Pit; 4) East Pit; 5) Sand Channel; 6) Pele's Pit.

Pele's Vents—previously the prime locus of Loihi's hydrothermal activity—collapsed, forming a pit crater (Pele's Pit) approximately 600 m in diameter with its bottom 300 m below the previous surface. Portions of the West Pit rim and areas to the north have faulted down several meters toward the summit center, bisecting Pisces Peak. The Sand Channel, a preexisting large fissure extending westward from the East Pit, now intercepts Pele's Pit. East pit crater has shallowed by ~23 m, apparently as a result of infilling by mud. Evidence of recent fracturing, hydrothermal activity, and emplacement of black sands was noted along the upper south rift.

Surveys on the northern half of Loihi revealed no obvious changes. The collapse forming Pele's Pit exposed massive columnar jointed flows and hydrothermally lithified talus, which now form large spires on the near-vertical north face of Pele's Pit. Much of the southern summit appears to be newly shaken; pillow surfaces that were previously light brown are now littered with broken weathered pillow debris and fresh-appearing glassy rocks (Figure 3). The glassy rocks decrease in size away from west pit, suggesting ejection of the rocks from that crater, but the edges of Pele's pit are not covered with new rocks, which suggests that it formed slowly, possibly over a period of days.

Hydrothermal Plumes

Intense hydrothermal plumes resulting from the seismic event were studied using hydrocasts (vertical water sampling at a single site) and tow-yos (sampling by an instrument package that is raised and lowered behind a moving ship). Temperature anomalies of 0.5° C were common during the RRC in the water column around the summit at depths of 1050–1250 m, with anomalies of 0.1°C at distances greater than 8 km (Figure 4). In contrast, mid-ocean ridge plumes typically have maximum anomalies of 0.02–0.1°C, although event plume anomalies of up to 0.3°C have been observed [e.g., *Baker et al.*, 1987]. One surprise was the observation of a very intense plume at 1600–1800 m depth at a "background" station 50 km northeast of Loihi. A marked decrease in pH (0.2 units) and a remarkable ^3He enrichment of 150% were measured, suggesting an injection of magmatic gases to the water column during a large short-lived but rapidly cooled volcanic episode well below the summit of Loihi during the early stages of the seismic event.

Sharp vertical temperature and chemical gradients measured by RRC hydrocasts showed that hydrothermal fluids were accumulating in the bottoms of the pit craters. Anomalies of up to 3.5°C and 0.65 psu salinity were measured. Tracers of hydrothermal and volcanic emission in the pits were greatly enriched with respect to ambient sea water: Fe = 45,000x (45 μM), Mn = 29,000x (5.7 μM), CH_4 = 560x (280 nM), H_2 = 100x (20 nM), and TCO_2 = 7x (17 mM). The pH of this water was 5.6 (as compared to the ambient value of 7.8), which was likely due to the acidity of the injected magmatic CO_2. No sulfide smell was detectable, suggesting that the vent fluids were not in contact with the basalt at high enough temperatures or not long enough for H_2S to form.

LONO hydrocasts showed that temperature anomalies within Pele's Pit had decreased to 0.6°C after the RRC. Nevertheless, a hydrocast 1.2 km west of the summit detected many plumes with anomalies up to 0.10°C between 1050 and 1330 m, the largest coming from the intense venting near the bottom of Pele's Pit. The hydrothermal plume was detected 12 km west of the summit.

Hydrothermal Vents

Vent fields with temperatures of up to 77°C were discovered during the LONO cruises, one near the bottom and two on the north wall of Pele's Pit, two on the south rift, and one west of the summit (Figure 2). Venting was generally diffuse, exiting through nontronite-coated talus, although 1–3-m-wide fissures vented large volumes of water in the south rift vent area. Rocks bearing several high-temperature sulfide minerals were collected, which suggests that vent waters were hot (at least 250°C) when these deposits formed. This apparent decrease in temperature with time will be verified by temperature recorders and samplers emplaced for yearlong sampling of vent fluids.

Fluid samples were collected from seven vents. Gas content of the fluids was >52 mmole/kg, or 17 times the background seawater value. As noted in previous Loihi vent fluids [*Sedwick et al.*, 1994], CO_2 continues to be the dominant vent fluid gas, but its ratio to dissolved silica and heat decreased dramatically during the last decade: dissolved CO_2/ heat ratios decreased by about 30% between 1987 and 1992. The CO_2/heat ratios from the LONO cruise continued this trend, decreasing by over 90% relative to

Fig. 3. A breccia deposit containing a mix of nontronite-covered pillow fragments, fresh talus, and glassy shards at the edge of Pisces Peak (cliff in the background). This photograph was taken on the first Pisces V dive after the July 1996 event.

fluids collected between 1987 and 1992. These decreases are ascribed to progressive degassing from a magmatic intrusion. The much lower CO_2 values in the fluids collected in 1996 (~10 mmol/kg CT (total carbon), compared with ~300 mmol/kg CT in 1987 and ~200 mmol/kg CT in 1992) could reflect a continuation of this degassing trend or indicate that the magma supplying gases to the hydrothermal vents degassed substantially during the seismic event.

Petrology

Rocks and sediment were collected using the Pisces V submersible during the RRC and LONO cruises. The RRC sampled a "young" breccia on the western rim of West Pit (Figure 3), yielding three of the freshest lavas collected from Loihi. The LONO cruises collected talus fragments, some with sulfides (pyrite, bornite, sphalerite) and amorphous silica coatings, in situ lavas, and sediment. The sediment consists of coarse black sand, Pele's hair, and paper-thin bubble-wall fragments produced by the reaction of fluid lava with seawater, mixed with planktonic foram tests.

The RRC lavas are low SiO_2 tholeiites, typical of recent Loihi lavas [*Garcia et al.*, 1995]. They contain 1 to 2 vol. % clinopyroxene phenocrysts—which are rare in Hawaiian tholeiites—and two chemically distinct populations of olivine, which are in equilibrium with the two end member glassy rock compositions (that is, 8.2 and 10.3 wt% MgO). The clinopyroxenes contain strongly resorbed olivine and reversely zoned rims. This reverse zoning and two olivine populations indicate magma mixing, probably just before or during eruption. The olivine inclusions in clinopyroxene apparently formed at moderate pressures (~2.8 kbars) based on modeling of equilibrium crystallization of the observed rock compositions using the MELTS program [*Ghiorso and Sack*, 1995], which models rock melts. Analyses of RRC glasses yield trace element ratios (e.g., La/Yb) that continue a decreasing temporal geochemical trend for young Loihi tholeiites [*Garcia et al.*, 1995], supporting the hypothesis that they were recently erupted. These results indicate that the RRC rocks are young and were stored at 8 to 9 km—compared to 2-6 km depth for the nearby Kilauea magma chamber [*Klein et al.*, 1987]—before being mixed with a more mafic magma, which may have triggered the eruption of these rocks.

Radiochemistry

Preliminary ^{210}Po-^{210}Pb ages of two fresh-appearing RRC lavas indicate that they were almost certainly erupted sometime between early 1996 and the seismic event and probably were erupted a month or more apart. The ^{210}Po-^{210}Pb dating technique can provide ages of lavas erupted within the past 2.5 years [*Rubin et al.*, 1994]. Although these ages are preliminary, one or both may pre-date the seismicity event at Loihi by several months. Final ages will not be available until late 1997 because three to four separate analyses of ^{210}Po in a lava—each several months apart—are required to establish the lava's age.

Pb, Nd, and Po isotopes and the abundances of these and a number of volatile trace metals have been analyzed in RRC particle-enriched sea water (0.22 g/L) to detect anomalies expected from magmatic degassing of metals. Particulates show 10-33x enrichments of the volatile elements Po, Pb, Mo, W, Sb, As, Tl, and Te relative to Loihi summit lavas, a Pb isotopic composition indistinguishable from Loihi summit lavas, and an Nd isotopic composition that represents a maximum admixture of 10% sea water Nd with Loihi isotopic compositions. Together, these compositions strongly suggest a young Loihi rock-source for the particulates overprinted by a Loihigenic magmatic volatile enriched effluent (rather than local sea water) as the primary source of the enriched trace elements adhering to the particulates.

Shipboard ^{222}Rn analyses during the LONO cruises revealed elevated water column Rn activities (60-75 dpm/100 L) at 1000–1300 m depth and up to 30,000 dpm/100 L in the vent fluids. This radon distribution is similar to that of 1993, indicating that any potential eruptive pulse of Rn in August had already passed by early October.

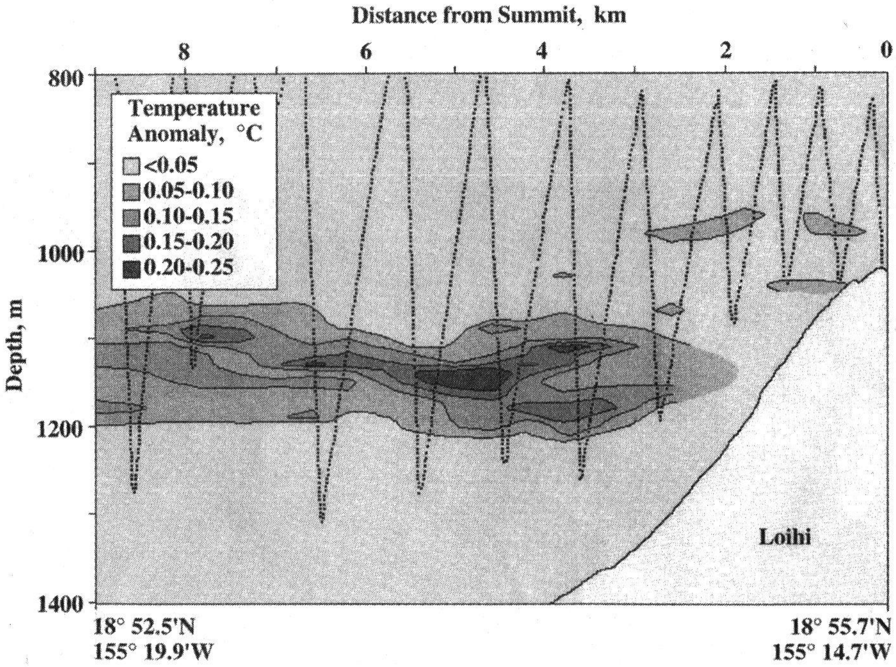

Fig. 4. This tow-yo cross section taken during the Rapid Response Cruise shows the thermal plume west of Loihi (see Figure 2 for track).

Microbiology

Microbial mats surrounding hydrothermal vent orifices were abundant and were observed to reform within a day following sampling. Samples of mats from different sites were brought into enrichment culture using a method designed to focus the bacteria along opposing iron-sulfur versus oxygen gradients. These enrichments are being purified for physiology studies. Additionally, microbial mat samples were collected to address questions such as community succession. The majority of the taxa observed previously in Loihi microbial mats are most closely related to mesophilic iron- and sulfur-oxidizing bacteria [*Moyer et al.*, 1995].

The geomorphology and venting character of Pele's Pit has created a "chemostatlike" reservoir. As the entire circumference of Pele's Pit is comprised of relatively steep walls rising ~200 m from the pit bottom, fluid exchange is restricted to vertical mixing, presumably influenced by hydrothermally induced buoyant updrafts and ambient cold water downdrafts. These conditions may contribute to the high microbial biomass observed within the pit.

Macrobiology

Loihi Seamount hydrothermal vent systems lack the luxuriant macrobenthic communities characteristic of vents from mid-ocean ridges. The only two vent-specific macrofaunal species described from Loihi have been a bresiliid shrimp, Opaepele loihi [*Williams and Dobbs*, 1995], and a lineage of pogonophoran worm. The postevent dives, however, reported seeing no bresiliid shrimp and only one pogonophoran worm. Thus the long-term impact of the 1996 event on these species is unknown.

While the synthesis of these data will take several years to complete, the value of quickly obtaining a diverse database is clearly demonstrated. Dives planned for the upcoming two years, and the concurrent establishment of an underwater observatory at Loihi, should more fully document these and future events at this active submarine volcano.

Acknowledgments

The authors would like to thank all of those who helped make these cruises possible and timely, including the School of Ocean and Earth Science Technology and University of Hawaii Administrations, the National Science Foundation, National Oceanic and Atmospheric Administration, the U.S. Geological Survey's Hawaiian Volcano Observatory, and in particular the captain and crew of the R/V *Kaimikai-o-Kanaloa*, and the Hawaii Undersea Research Laboratory dive team. We thank the following people for sharing their unpublished data with the authors: John Lupton, Irina Kolotyrkina, Terri Rust, Betsy McLaughlin, Jim Gharib, Jennifer Reynolds, Kevin Johnson, David Hilton, and Eric Olson. Figures 1, 2, and 4 were generated with GMT software. Please see the Loihi web site for more detailed information and author contacts: http://www.soest.hawaii.edu/GG/HCV/loihi.html.

The 1996 Loihi Science Team

F. K. Duennebier, N. C. Becker, J. Caplan-Auerbach, D. A. Clague, J. Cowen, M. Cremer, M. Garcia, F. Goff, A. Malahoff, G. M. McMurtry, B. P. Midson, C. L. Moyer, M. Norman, P. Okubo, J. A. Resing, J. M. Rhodes, K. Rubin, F. J. Sansone, J. R. Smith, K. Spencer, Xiyuan Wen, C. G. Wheat

References

Baker, E. T., G. J. Massoth, and R. A. Feely, Cataclysmic hydrothermal venting on the Juan de Fuca Ridge, *Nature, 329*, 149–151, 1987.

Garcia, M. O., D. J. P. Foss, H. B. West, , and J. J. Mahoney, Geochemical and isotopic evolution of Loihi volcano, Hawaii, *J. Petrol., 36*, 1647–1674, 1995.

Ghiroso, M. S, and R. O. Sack, Chemical mass transfer in magmatic systems IV, A revised and internally consistent thermodynamic model for the interpolation and extrapolation of liquid-solid equilibria in magmatic systems at elevated temperatures and pressures, *Contrib. Mineral. Petrol., 119*, 197–212, 1995.

Klein, F. W., R. Y. Koyanagi, J. S. Nakata, and W. R. Tanigawa, The Seismicity of Kilauea's Magma System, *U.S. Geol. Surv. Prof. Pap. 1350*, 1019–1186, 1987.

Moyer, C. L., F. C. Dobbs, and D. M. Karl, Phylogenetic diversity of the bacterial community from a bicrobial mat at an active hydrothermal vent system, Loihi Seamount, Hawaii, *Appl. Environ. Microbiol., 61*, 1555–1562, 1995.

Rubin, K. H., J. D. Macdougall, and M. R. Perfit, ^{210}Po-^{210}Pb dating of recent volcanic eruptions on the sea floor, *Nature, 368*, 841–844, 1994.

Sedwick, P. N., G. M. McMurtry, D. Hilton, and F. Goff, Carbon dioxide and helium in hydrothermal fluids from Loihi Seamount, Hawaii, USA: Temporal variability and implications for the release of mantle volatiles, *Geochim. Cosmochim. Acta, 58*, 1219–1227, 1994.

Williams, A. B., and F. C. Dobbs, A new genus and species of caridean shrimp (Crustacea: Decapoda: Bresiliidae) from hydrothermal vents on Loihi Seamount, Hawaii, *Proc. Biol. Soc. Wash., 108*, 228–237, 1995.