Final Report: NOAA Office of Ocean Exploration

I. OVERVIEW

Grant Number:

Amount of funding from Ocean Exploration: $84,097

Project Title: Macrobiological characterization of Vailulu'u Seamount, an active volcano off American Samoa

Area of Operation: Vailulu'u Volcano and Tau Island, American Samoa

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Participating Institutions:

University of Oregon, Washington State University, University of Sydney (Australia), Scripps Instiutution of Oceanography, University of Hawaii, Oregon Health and Science University, Woods Hole Oceanographic Institution, University of Southampton (U.K.).

Award Period: June 1, 2005 to May 31, 2006

Period Covered by this Report: December 31, 2005 to May 31, 2006

II. SUMMARY

1. Abstract – 1-paragraph description of final report

We explored the crater and flanks of Vailulu'u seamount by submersible and discovered a new 300m tall, volcanic cone in the crater of this seamount that marks the location of the Samoan hot spot. This cone, named Nafanua, grew from the 1000m deep crater floor to a summit depth of 700m in less than four years and could reach the sea surface within decades. Hydrothermal vents fill Vailulu'u crater and the location of Nafanua coincide with a linear array of seismic epicenters that were observed in April-June 2000, possibly the precursor activity to the formation of Nafanua some time in the subsequent

four years. Hydrothermal vents fill the crater with a thick suspension of particulates and apparently toxic fluids that mix with seawater entering from the crater breaches. Low-temperature vents form Fe oxide chimneys in many locations and up to one-meter thick layers of hydrothermal Fe floc on Nafanua. High temperature (81°C) hydrothermal vents in the northern moat (945m water depth) produce acidic fluids (pH=2.7) with rising droplets of (probably) liquid CO2. The Nafanua summit vent area is inhabited by a thriving population of eels (*Dysommina rugosa*) that feed on midwater shrimp probably concentrated by anticyclonic currents at the volcano summit and rim. The moat and crater floor around the new volcano are littered with dead metazoans that apparently died from exposure to hydrothermal emissions. Acid-tolerant polychaetes (Polynoidae) live in this environment, apparently feeding on bacteria from decaying fish carcasses. Vailulu'u is an unpredictable and very active underwater volcano presenting a potential long-term volcanic hazard. Although eels thrive in hydrothermal vents at the summit of Nafanua, venting elsewhere in the crater causes mass mortality. Paradoxically, the same anticyclonic currents that deliver food to the eels may also concentrate a wide variety of nektonic animals in a death trap of toxic hydrothermal fluids

2. Purpose of Project:

a. Describe issue that was addressed:

The geology of the Samoan hotspot was incompletely understood and the biology of the system completely unknown at the beginning of this grant. Our goal was to explore this system for the first time, characterizing the geology and flow patterns around the volcano, mapping the distribution of the fauna, and investigating life-history and nutritional aspects of the resident organisms.

b. Describe/list the project objectives:

1) Describe the macrofaunal and megafaunal communities of Vailulu'u seamount, including both vent and non-vent fauna.
2) In collaboration with geologists, chemists and physical oceanographers, characterize the habitats in which these communities reside.
3) Using stable isotope techniques, conduct a preliminary assessment of trophic structure and possible chemosynthetic symbioses in the Vailulu'u ecosystem.
4) Using histological and embryological techniques, characterize life-history attributes that might influence dispersal to and from other vent sites.
5) Compare non-vent faunas on the flanks of Vailulu'u with the faunas at similar depths on the much older slope of nearby Ta'u Island.
6) Deploy and recover settlement substrata to examine the possible effects of pulsed hydrothermal fluid delivery on recruitment.

7) Collect and archive metazoan samples for systematics and molecular genetics, making these samples available to colleagues who are actively working on population genetics and biogeography of vent systems at other sites (e.g., Lau, Fiji, Marianas basins) in the Southern and Western Pacific.

3. Approach:

a. Describe the work that was performed

We carried out two cruises aboard the Kaimikai O' Kanaloa: a four day cruise in March - April and an 9 day cruise in June/July including a total of 12 scientists: C. Young and H. Staudigel (co-chief scientists); Brad Bailey, Sandra Brooke, Stan Hart, Lisa Haucke, Ian Hudson, Ray Lee, Adele Pile, Brad Tebo, Alexis Templeton. The second cruise we also included Richard Smith from the Australian Broadcasting Company. These dives were devoted to the exploration of the hydrothermal and biological systems of Vailulu'u and the deployment and retrieval of exposure experiments, current meters and temperature and light backscattering recorders. Video was used to map the submersible tracks, and these maps were supplemented with video records from ROV dives during evening hours.

b. Describe how the project was organized and managed

The collaborative project was managed jointly by Craig Young, who took responsiblility for the macrobiological work, and Hubert Staudigel, who managed the physical science components. Both teams collaborated on cruise mobilization and demobilization in Hawaii. Adele Pile (University of Sydney) had additional funding from the Australian government, so she was included in shipboard decisions. The University of Oregon administered the grant, incuding a subcontract to Ray Lee at Washington State University, who ran the isotope analyses.

c. Describe how data was organized, processed, and archived

The Hawaii Undersea Research Program archives and processes tracking data, submersible CTD data, underwater photographs and video data through their normal data logging system. Geological information about the volcano and the Samoan Hotspot is now available in the Seamount Biogeochemical Network website at Earthref.org. Biological data (isotope values, photographs, etc.) are still being processed for publication.

4. Findings:

a. Describe actual accomplishments and findings

Discovery of Nafanua volcano and "Eel City". In April, 2006, immediately before the first dive of the first cruise, a sonar track over the Vailulu'u caldera revealed a new volcanic cone (we named it Nafanua for the Samoan war god) emerging from the crater floor and rising more than 300 meters. This crater was not present during prior multibeam surveys in 2002 (Figure 1).

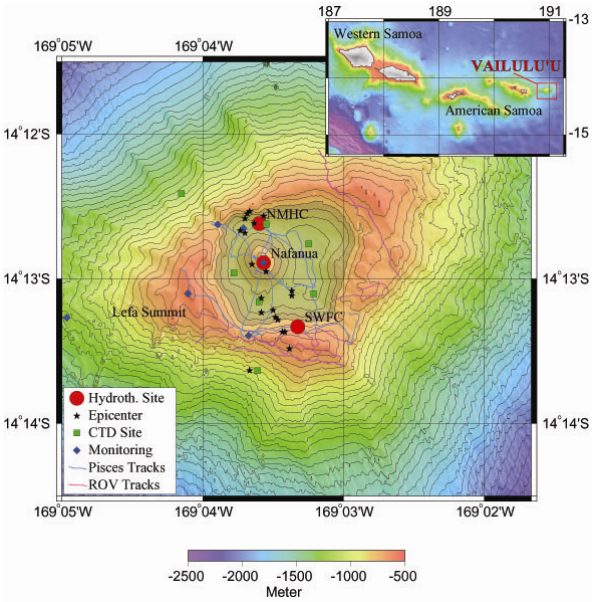

Figure 1. Multibeam map of Vailulu'u Seamount, showing newly discovered Nafanua volcano. Positions of hydrothermal vents, deployment sites for monitoring equipment, and Pisces and ROV tracks are noted.

Dives on the cone revealed the presence of warm water vents and large microbial mats that were colonized by large numbers of eels, which were subsequently identified as *Dysommina rugosa*, a species of deep-sea synaphobranchid known from both the Atlantic and Pacific oceans, but never before reported from hydrothermal vents. Details of the discovery and the geology of the new volcanic cone, Nafanua, are given in Staudigel et al. (2005) and the eel's presence at vents is described in the latest edition of Handbook of Hydrothermal Vent Fauna (Young and Biscoitto, 2006). Few other organisms were found on the summit of Nafanua. There were no epifaunal invertebrates, but a small number of copepods and polychaetes were found apparently residing in the mat itself. These had δ13C: values of -13 and -21 for the scale worm and the copepod respectively, and both animals had a δ15N value of 8.

Diet of the Eels. Eel tissues and samples of the microbial mat in which they reside were collected for later energetic and isotopic analyses carried out in the laboratory of Ray Lee. The mat was only 0.7% C and 0.04% N, which is 2-3 orders of magnitude lower than the C and N values of metazoan animals such as eels. Moreover, the Carbon and Nitrogen isotope values of the eels were significantly different from those of the mat (eels: δ13C: -17.7to -16.6, δ15N: 13.9 to 15.9; mat: δ13C: -24.9 to -18.1; δ15N: 2.7 to 9.9). These data all suggest strongly that the eels are not obtaining nutrition from the mats in which they reside. On the June cruise, after attempting a number of different methods for trapping eels, we captured 7 specimens using a custom dip net

Figure 2. Photomicrograph showing midwater shrimp appendages in the gut contents of *D. rugosa.*

manipulated by the mechanical arm of the sub. Gut contents of several of these consisted entirely of bright red midwater shrimp (Figure 2). It was concluded that the eels feed upon midwater shrimp delivered to them by currents that move over the top of the volcanic cone.

Dead Zone. At a depth of 1000 meters, on the Northeast floor of the crater, we encountered an area of elevated (81°C) temperatures and high salinity where bubbles of (probably) liquid CO_2 were streaming from the substratum. A water sample taken in this area revealed a pH of 2.7. The entire region was littered with the dead carcasses of fish, crustaceans and squids, mostly species that live in the overlying water column and that apparently met their demise when encountering this zone of toxic fluids. Only one living animal was found here: a polynoid polychaete (yet to be identified, Figure 3) that was apparently grazing on either the carcasses of dead fishes or on the bacteria that was found on these fishes. Only a single specimen was collected and retained, and it is now in the hands of an expert on this group.

Figure 3. Unidentified polynoid polychaete that is able to tolerate the extreme conditions of the dead zone.

Species Inventories and Habitat Mapping. We have identified most of the deep-sea species that were encountered both within the crater and on the western flank and southern rim. One of the most remarkable was a small sponge, *Abyssocladia bruuni*, that lives in enormous numbers at the place where tides create high flows on the southern breach. Detailed mapping of the fauna is currently underway. Figures 4 and 5 show examples of the preliminary maps, indicating dramatic patterns of faunal replacement associated with depth and with fluids from within the caldera. The zonation patterns of some species appear to be related to the vertical pumping of particle-laden vent fluids.

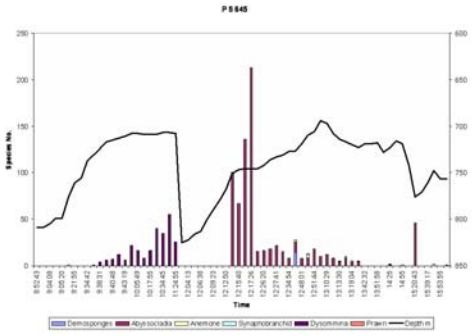

Figure 4. Distributution of animals on a transect from the summit of Nafanua through the southwest breach, showing a large peak in abundance of the sponge *Abyssocladia bruuni*.

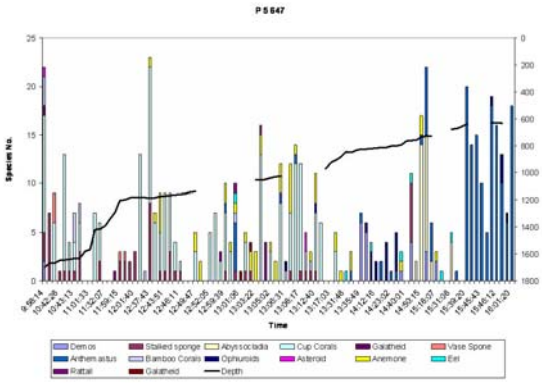

Figure 5. Transect from 1700m to the summit on the western flank, showing patterns of species replacement.

Stable Isotope analysis. Samples were taken from a large assortment of animals for stable isotope analysis. Orange microbial mat exhibited delta $\delta^{15}N$ and $\delta^{13}C$ values consistent with local chemosynthesis. $\delta^{15}N$ values ranged from 2-6 ‰, $\delta^{13}C$ ranged from -25 to -18 ‰. These values (particularly δ15N) differ considerably from non-vent deep sea consumers which exhibit □□N values ranging from 11 to 17 (ave 15) ‰ and $\delta^{13}C$ values ranging from -25 to -18 (ave -20) ‰ (Van Dover et al. 1994). The light $\delta^{15}N$ of bacterial mat is strong evidence for chemosynthesis. $\delta^{13}C$ values of Vailulu'u bacterial mats are inconsistent with methane based chemosynthesis that would result in lighter values.

The stable carbon and nitrogen isotopic compositions of the orange mat are quite variable, suggesting that there are site specific differences. Variability in isotopic composition is likely due to differences in diffuse flow fluid chemistry and/or microbial C and N assimilation physiology. Similar variability has been observed in other vent systems but has not been systematically investigated.

The isotopic composition of the scaleworm and copepod collected within the bacterial mat were similar to mat values, exhibiting a trophic enrichment consistent with bacterial mat as a source of dietary C and particularly N. In contrast, isotope values of deep sea fauna collected on summit and the outer slope of Vailulu'u, were clearly isotopically heavy and similar to average values for non-vent deep sea fauna. This indicates that vent derived C and N is not important for many of these organisms. Some organisms were intermediate (*Anthomastis* coral from summit, Pink coral from slope) in isotopic composition indicating that they may consume particulate material that is derived from vent C and N. A plot of all isotope data (Figure 6) indicates clear differences in isotope composition between animals associated with the venting on Nafanua and animals outside the influence of vent fluids.

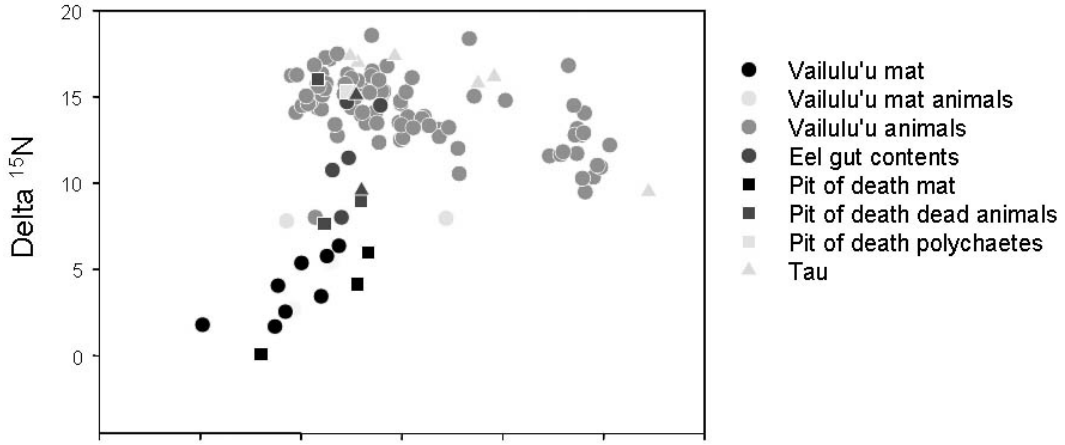

Figure 6. Isotope values of organisms collected from various habitats within the caldera and on the outer flanks.

Because the cloud of particulates from the volcano are known to move up and down on the outer flanks of the volcano with tidal action, we collected animals of

several different trophic modes from above and below this area of influence and ran isotopic comparisons between zones. Two examples of these data are shown in Figure 7. Brittle stars, which are deposit feeders, showed no clear difference in either nitrogen or carbon isotopes among the three zones. The micropredatory suspension feeding octocoral *Anthomastus,* however, had heavier nitrogen signals above and within the cloud than below.

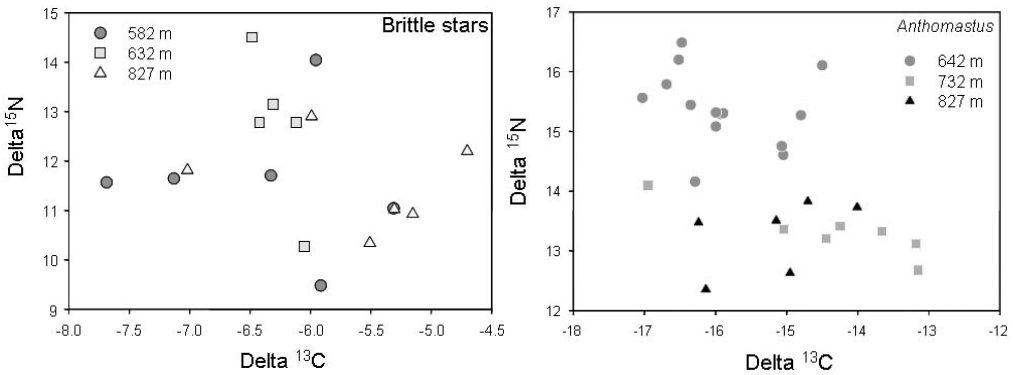

Figure 7. Carbon and Nitrogen isotope values of ophiuroids (left) and octorocals (right) collected from Lefa summit, from the upper flank where volcanic particulates are known to occur, and from below the particulate cloud.

b.. Inventory of activities (number of submersible dives, CTD, net tows, etc.)

We had 2 cruises, one in April and one in June of 2005. On the first cruise, we did four Pisces V dives. On the second cruise, we did 6 dives and 2 ROV lowerings.

c. Inventory of samples collected.

Specimens are still being identified and inventoried. A final list will be available after taxonomic authorities have completed work that is still underway.

d. Describe/list resulting publications, Web sites, presentations, etc.

Publications on isotopes, habitat mapping, eel biology and otolith chemistry are currently in preparation. The following two contributions have already appeared.:

Staudigel, H., S. Hart, A. Pile, B. Bailey, E. Baker, S. Brooke, L. Haucke, I. Hudson, D. Jones, A. Koppers, J. Konter, R. Lee, T. Pietsch, B. Tebo, A. Templeton, R. Zierenberg, C.M. Young (2005). Vailulu'u Seamount, Samoa: life and death on an active submarine volcano. Proceedings of the National Academy of Science 103:6448-6453.

Young, C.M. and M. Biscoitto. *Dysommina rugosa.* In, D. Desbruyeres, M. Segonzac and M. Bright, eds., Handbook of Hydrothermal Vent Fauna. Denisia, Vienna.

The results of the cruise, particularly the discovery of "eel city" have appeared on dozens of websites, including the following, which are only a few of those currently available:

http://earthref.org/SBN/index.html

http://www.oceanexplorer.noaa.gov/explorations/05vailuluu/welcome.html

http://www.whoi.edu/home/about/currents9_no1_vailulu.html

http://www.whoi.edu/oceanus/viewArticle.do?id=7142

http://www.volcano.si.edu/world/volcano.cfm?vnum=0404-00-

http://earthref.org/cgi-bin/er.cgi?s=http://earthref.org/SBN/vailuluu/main.htm

http://www.geolsoc.org.uk/template.cfm?name=Vailulu

http://www.pnas.org/cgi/content/abstract/103/17/6448

http://www.signonsandiego.com/news/science/20060118-9999-lz1c18volcano.html

Results of this project provided the centerpiece for a symposium on seamounts at the AGU meeting in San Francisco during December, 2005, with two talks and abstracts. Two talks also were presented at the Seamount Biogeochemical Symposium at Scripps in 2005, and two additional talks were presented at the International Vents and Seeps meeting in La Jolla in September, 2005. The results have been the topic of three seminars, including one public lecture, in Oregon and one in Australia of which we are aware.

The news of eel city and Vailulu'u volcano was immediately picked up by Associated Press and provided the basis for hundreds of newspaper, radio and television spots worldwide. The story was identified by Discover magazine in their January 2006 issue as one of the top 100 science stories of the year.

We included on the second cruise an Australian film maker, Richard Smith, who is currently working on a documentary film on the Vailulu'u cruises for the Australian Broadcasting Corporation. It is anticipated that this will eventually be made available to the Discovery Channel in the U.S.

e. Location and status of data archive and/or sample storage

Isotope samples were taken by Ray Lee and are in his posession at Washington State University. Invertebrate samples were taken as vouchers by Craig Young and are in his laboratory at the University of Oregon. Otoliths taken from the eels

for microchemistry analysis are in the posession of Adele Pile at the University of Sydney. Voucher specimens of the eels were originally sent to Ted Piesch at the University of Washington for identification and are now in the National Museum of Natural History, Washington D.C. A few voucher specimens of invertebrates have been sent to taxonomic authorities and remain in their possession.

III. Evaluation:

1. Accomplishments – Explain special problems,

There were no special problems. All work was accomplished as anticipated and scheduled.

2. Expenditures:

Because of unanticipated increases in travel costs, we spent $4,516.79 more in travel than was budgeted. This overexpenditure included an unbudgeted trip to Honolulu to load and mobilize the ship, as required by HURL. We compensated for these increased travel costs by a reduction in expenditures for supplies and shipping ($2,123.29 less than budgeted) and in personnel costs ($1825.53 less than budgeted). When eels were discovered on the first cruise, we constructed custom eel traps for the second cruise, which were not budgeted. Because of the high travel costs, we were not able to cover the cost of these eel nets with the grants, so paid for them from institutional resources.

3. Next Steps:

a. Planned or expected reports (professional papers, presentations, etc.)

Most of the biologists working on this project met during the Deep-sea Biology Meetings in Southampton, U.K. during July, 2006 to outline the next steps. Various teams are working on 4 additional papers as outlined in the "publications" section above. These should all be completed by early 2007.

b. Brief description of need for additional work, if any.

The outer flanks of the Vailulu'u volcano remain mostly unexplored and further exploration is desirable. Perhaps the most intriguing biological discovery was of a polynoid polychaete that lives in extreme conditions in the dead zone. Further work on the physiology and reproduction of this amazing species would be very exciting.

Prepared By: Craig M. Young October 6, 2006
Principal Investigator Date