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Expedition Reveals Changes in Lau Basin Hydrothermal System

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The Valu Fa Ridge (VFR) in the southern Lau Basin—located behind the westward-dipping Tonga-Kermadec subduction zone—was one of the earliest targets to be explored for hydrothermal activity in the southwestern Pacific Ocean (Figure 1). In 1989, the French-German dive program NAUTILAU (*Nautile*-Lau) discovered active hydrothermal fields venting high-temperature fluids with high acidity accompanied by massive ore deposits in this area [*Fouquet et al.*, 1993].

In September–October 2004, the SWEEP VENTS (SouthWestern Edge of Pacific hydrothermal vents) expedition explored and sampled the hydrothermal systems of the VFR using the deep submergence research vehicle (DSRV) *Shinkai 6500*. The 2004 *Shinkai* dives focused on the geobiological and geochemical character of the deep-sea hydrothermal vent ecosystems of the Valu Fa Ridge and shed new light on these hydrothermal fields 15 years after their discovery. These 2004 dives were the first to revisit this area, and have been followed by further dive programs and continued research.

Fifteen years ago, vigorous hydrothermal activity with fluid temperatures exceeding 340°C was discovered at the Vai Lili field (22°13.0' S, 176°36.5'W, depth = 1720 meters) on the northern section of the central VFR (Figure 1). But the 2004 SWEEP VENTS expedition found only weak shimmering water with a temperature of 88°C discharging from the foot of an oxidized chimney (Figure 2a) as well as diffuse flows associated with yellow patches of iron-oxides (Figure 2b). The lower fluid temperature demonstrates that the activity has declined significantly during the intervening time.

In contrast to the dying Vai Lili field, about four kilometers north SWEEP VENTS located another hydrothermal field, Mariner field (22°10.8'S, 176°35.1'W, depth = 1910 meters), with numerous smokers (Figures 2c and 2d) venting high-temperature fluids (T = 365°C) with low pH (2.4–2.8 at room temperature measurement). The contrast between these two hydrothermal fields may be an indication of the instability of hydrothermal activity in back-arc settings, where magma is located at shallow depths and its significant influence would be expected.

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Evolution of Hydrothermal Activity in the Back-Arc Spreading Center

The VFR is the shallowest portion of the Eastern Lau Spreading Center (ELSC) at its southern end. Petrologic studies have revealed felsic volcanic activity ranging from basalt enriched in lithophile elements to andesite, both of which have abundant vesicles due to the high gas content of the magma. During the 1989 NAUTILAU expedition, three active hydrothermal fields were discovered along the VFR: Hine Hina in the south, Vai Lili in the central VFR, and the White Church fields in the north [*Fouquet et al.*, 1993].

Submarine hydrothermal systems develop where seawater that has penetrated into the crust is heated by magma to ascend along fault lines. The fluid circulation transports to the seafloor not only heat but also substances used by microbes in the hydrothermal environment. As discussed by *Kelley et*

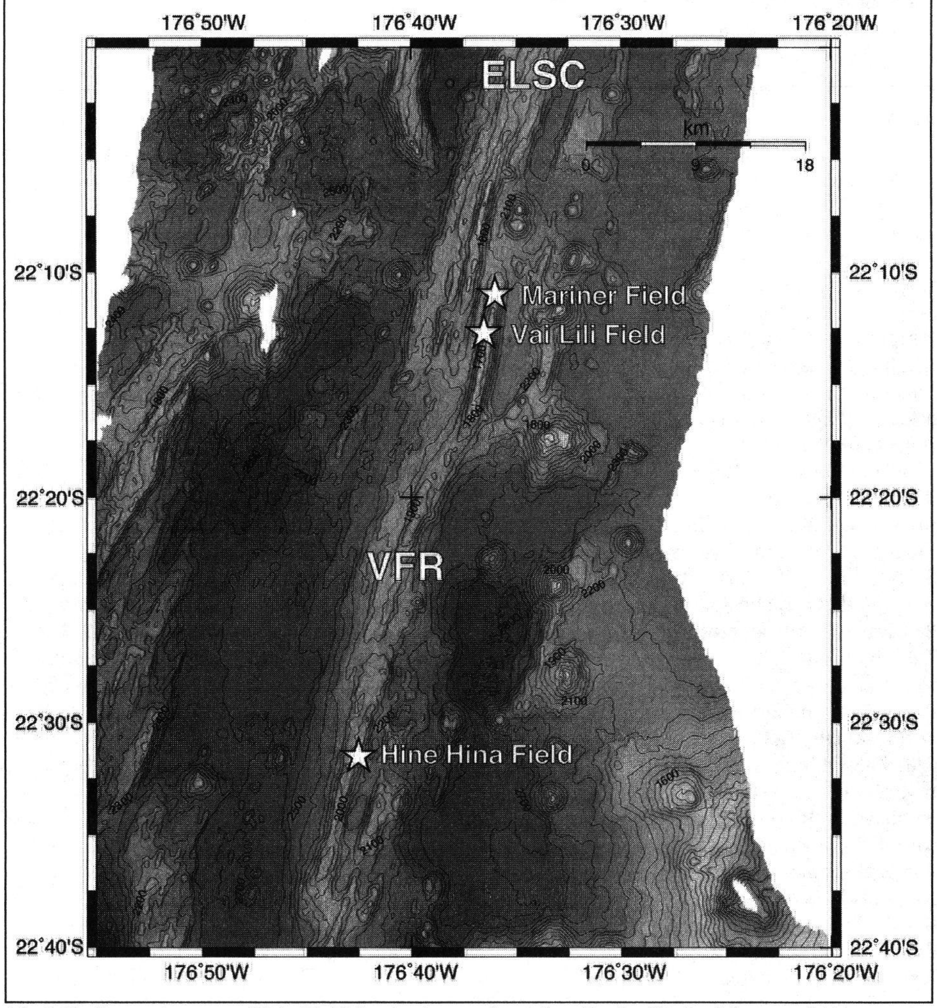

Fig. 1. Bathymetric map of Valu Fa Ridge in the southern Lau Basin (derived from multi-beam swath-mapping survey conducted by the research vessel Yokosuka*) and locations of active hydrothermal fields.*

al. [2002], magmatic events can drastically increase the content of volatile species degassed from magma and incorporated into the hydrothermal fluids, thus forcing a shift in the associated microbial ecosystem. Hydrothermal fields in the central VFR, where the presence of a crustal magma body at shallow depths has been demonstrated by seismic tomographic study [*Day et al.*, 2001], can provide an excellent place to test the influence of magmatic volatiles on the evolution over time of the geochemical and geobiological character of hydrothermal activity. The influence of the significant contribution of magmatic volatiles on the active hydrothermal systems on the VFR has been previously explained in terms of strong acidity and sulfur isotopic composition [*Fouquet et al.*, 1993; *Herzig et al.*, 1998].

During the SWEEP VENTS dive program, which was operated by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and also designated as the YK04-09 Nirai Kanai cruise of the research vessel *Yokosuka*, 18 dives were conducted on the VFR with the submersible DSRV *Shinkai 6500*. Samples of hydrothermal fluids were collected using the gas-tight WHATS (Water and Hydrothermal-fluid Atsuryoku Tight Sampler) fluid sampler and processed on board for gas extraction, as well as for geochemical and microbiological analyses.

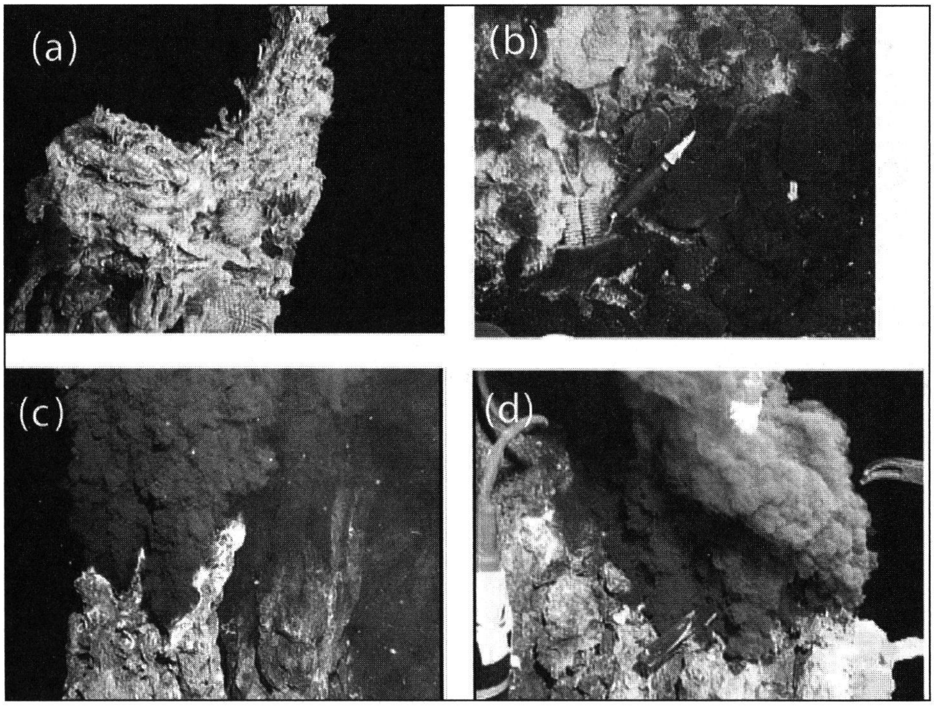

Fig. 2. Photos obtained with Shinkai 6500 *showing hydrothermal activity on the Valu Fa Ridge. (a) An oxidized chimney discharging 88°C fluid in the Vai Lili field. (b) Diffuse flow (T = 40°C) in the Vai Lili field. (c) Vigorous venting from a black smoker (T = 365°C) in the Mariner field. (d) Deployment of the ISCS in the vent orifice in the Mariner field. Original color image appears at the back of this volume.*

Dying Hydrothermal Activity in the Vai Lili Field

The Vai Lili field lies on the upper western flank of the ridge axis on the shallow northern section of the central VFR. When discovered in 1989, this field was reported to have vigorous fluid ventings with abundant black and white suspended materials [*Fouquet et al.*, 1993]. In addition to the numerous smokers with fluid temperatures up to 342°C, extensive diffuse discharge was observed forming a continuous halo of iron and manganese oxides distributed about 400 meters along north-south trending normal faults.

During the 2004 SWEEP VENTS expedition, it was evident that the hydrothermal activity at the Vai Lili field had declined significantly during the intervening 15 years. Diffuse flows (T = 35–50°C and pH = 6.5), often accompanied by orange-yellow patches of iron oxides (Figure 2b), were still present throughout the area. The highest fluid temperature was only 88°C, found as a weak shimmering flow issuing from the base of an oxidized chimney in the center of the Vai Lili field (Figure 2a).

In spite of the lower fluid temperature, the hydrothermal reservoir appears to still exist based on fluid chemistry. The collected samples show a linear relationship among the concentrations of chemical species such as chloride, potassium, and total gas versus that of magnesium (Figures 3a–3c), suggesting that both the shimmering fluid and the diffuse flow can be explained adequately as a simple mixture of the hydrothermal fluid end-member and seawater. On the other hand, in the relationship between calcium and magnesium concentrations (Figure 3d), the weak shimmering fluid (T = 88°C) samples (open squares) and the diffuse flow samples (solid squares) show different trends. Taken together with a similar trend found in strontium and sulfate concentrations, these discrepancies are evidence for subseafloor precipitation of anhydrite ($CaSO_4$) caused by mixing of the hydrothermal fluid with entrained seawater. The low concentrations of iron (70 micromoles per liter (μmol/l); Figure 3e) and hydrogen sulfide (30 μmol/l; Figure 3f) are consistent with precipitation of sulfide minerals as well as anhydrite.

The depletion of hydrogen sulfide in the Vai Lili hydrothermal fluid should have considerable impact on the microbial and macrofaunal communities. The typical microbial components dominating active hydrothermal fields (such as members of *Thermococcales*, *Methanococcales*, *Aquificales*, and *ε-Proteobacteria*) were not detected by culture-dependent analysis from the samples collected at Vai Lili during the 2004 SWEEP VENTS expedition. However, ribosomal RNA gene sequences of *Thermococcales* (a hyperthermophilic archaea, which grows above 80°C) were recovered by culture-independent molecular analysis from the samples obtained by in situ colonization devices (ISCS) deployed in the diffuse flow. In addition, the archaeal and bacterial ribosomal RNA phylotypes, which had been found specifically in dead chimneys, were also detected in the ISCS samples. Thus, the microbial communities in the diffuse flows at Vai Lili field may contain components representing both active and dead hydrothermal systems.

Newly Discovered Hydrothermal Activity in the Mariner Field

The Mariner field is located about four kilometers north of the Vai Lili field, where the northern end of the central VFR overlaps the northern VFR. During the 2004 *Shinkai* dives, vigorous fluid venting of black and white smokers was found here, together with clear diffuse fluids discharging from the base of chimneys. This activity was clustered within a hydrothermal field less than 100 meters in diameter (Figures 2c and 2d). The highest temperature of 365°C was confirmed at a black smoker in the center of the active field.

As evident in the magnesium diagrams (Figure 3), two distinct hydrothermal end-members are present: a vapor-rich fluid (downward pointing triangle) and a brine-rich fluid (upward pointing triangle). This is clear evidence for phase separation into a vapor and a liquid (brine), possibly reflecting high temperature in the vicinity of the magma. The strong acidity with pH as low as 2.4 (room temperature measurement) together with negative alkalinity (lower than 2 millimoles per liter) are commonly found in brine-rich and vapor-rich fluids, which suggests involvement of a strong acid, probably caused by the injection of magmatic volatiles into the hydrothermal fluid. These geochemical characteristics are similar to those observed at the Vai Lili field 15 years ago [*Fouquet et al.*, 1993], suggesting that both the Vai Lili and Mariner fields have been influenced by significant contributions of magmatic volatiles.

Since the Mariner field is presently active, microbiological analyses of the collected samples provided a measure of the physiological and phylogenetic diversity of the microbial communities. It was notable that methane-producing archaea were absent and the oxygen-tolerant hyperthermophilic *Aquifex* species were dominant in the chimney structures and even in the samples collected by the ISCS deployed in a 365°C black smoker. These signatures may represent a relatively oxidative and shallow zone of subseafloor biosphere and be in accordance with the idea that the hydrothermal activity is relatively recent.

Other Sites, Water-column Surveys, and Future Work

During the SWEEP VENTS expedition, one dive was devoted to revisiting the Hine Hina field (22°32.3'S, 176°43.1'W, depth = 1850 meters). This dive confirmed that prosperous macrofaunal communities found in 1989 were still present in 2004. Throughout the expedition, the faunal communities associated with hydrothermal activity on the VFR were found to have much lower abundance but similar diversity in species composition (shrimps, crabs, mussels, galatheids, limpets, polychaetes, and gastropods) compared with that reported 15 years ago [*Fouquet et al.*, 1993; *Desbruyères et al.*, 1994].

The ELSC has been selected as one of the Integrated Studies Sites (ISS) of the RIDGE 2000 Program. As part of this Lau Basin ISS work, several systematic water column plume surveys were conducted along the ELSC that either were coincident with the SWEEP VENTS expedition or preceded it. These water column surveys predicted that the activity in the Vai Lili field was dying, and also clearly identified the new robust activity at the Mariner site. Thus, these plume surveys contributed to the success of our *Shinkai* dive program reported here.

In addition to the hydrothermal sites along the Valu Fa Ridge, these plume surveys also identified many additional hydrothermal sources within the Lau Basin. Following the plume surveys, several dive programs have been conducted under the RIDGE 2000 program framework, and research into the findings is still ongoing. Because the Lau Basin spreading center displays large changes in crustal thickness, it can provide an excellent field to test the influence of magmatic volatiles on the evolution of hydrothermal activity. Those ongoing and future investigations using either manned or unmanned submersibles should provide valuable insights into the temporal and spatial variations of hydrothermal systems.

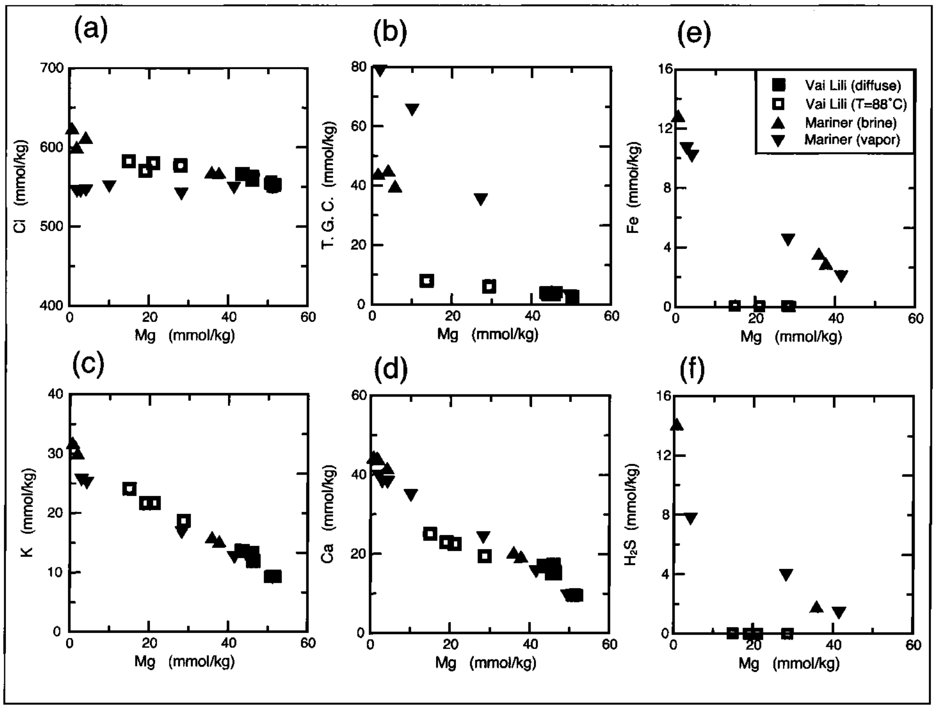

Fig. 3. Chemical composition of the samples from the Vai Lili field (squares) and from the Mariner field (triangles) in the central Valu Fa Ridge. The relationship of (a) chlorine (Cl) versus magnesium (Mg), (b) total gas concentration versus Mg, (c) potassium (K) versus Mg, (d) calcium (Ca) versus Mg, (e) iron (Fe) versus Mg, and (f) hydrogen sulfide (H_2S) versus Mg are plotted. Two distinctive trends among the Mariner fluid suggest phase separation (the vapor-rich fluid shows high Cl, K, Ca, and H_2S concentrations and low total gas concentration compared with the brine-rich fluid). Although the major element composition of the Vai Lili fluid is comparable to that of the Mariner fluid, the Ca concentration of the weak shimmering flow (T = 88°C) seems to show a different trend. Substantially low concentrations of Fe and H_2S of the weak shimmering flow are also notable. Those differences are attributed to subseafloor precipitation.

Acknowledgments

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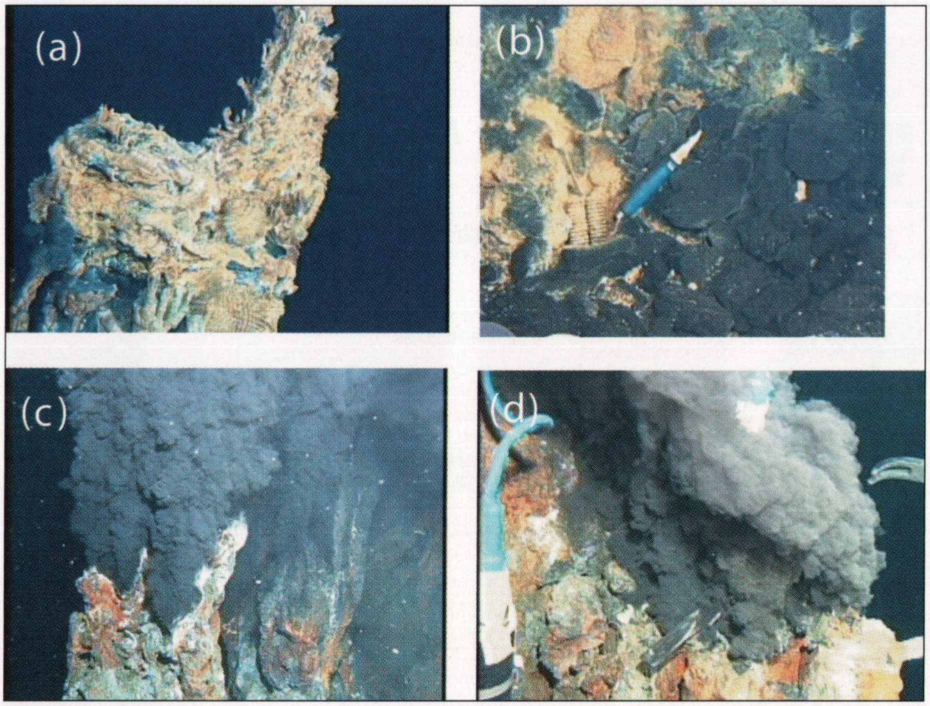

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