HYFIFLUX Cruise: German-French Cooperation for the Study of Hydrothermalism and Related Tectonism, Magmatism and Biology of the Active Ridges of the North Fiji Basin (SW Pacific)

Peter Halbach[1], Jean-Marie Auzende[2], Michael Türkay[3] and the Scientific Party[4] of the HYFIFLUX cruise.

[1] *Freie Universität Berlin Institut für Geologie, Geophysik und Geoinformatik, Malteserstrasse 74-100, Haus B, 12249 Berlin, Germany.*

[2] *IFREMER/CB, DRO-GM, BP 70, 29280 Plouzané, France, now at ORSTOM, BPA5, Nouméa, Nouvelle Calédonie.*

[3] *Forschungsinstitut Senckenberg, Senckenberganlage 25, Frankfurt A.M., D-60325, GERMANY.*

[4] *Scientific Party of HYFIFLUX cruise: Andreas Allspach, Klaus Becker, Norbert Blum, Olga Bonnier, Marc van Gerven, Margret Halbach, Andrea Koschinsky, Dietrich Lange, Maria Joao Madureira, Manolis Manutsoglou, Johann Mrazek, Ute Münch, Christelle Pratt, Erio Rahders, Ann Vanreusel, Steffen Richter, Thomas Seifert, Thoralf Spangenberg, Jochen Stenzler, Frank Thiermann and Reinhart Windoffer.*

The HYFIFLUX Cruise on the German *R/V SONNE*, was organized within the framework of an international co-operative project between the Free University of Berlin (P. Halbach), IFREMER (J.-M. Auzende) and other German universities. It is a multidisciplinary program for the study of hydrothermalism and associated geological, geochemical and biological processes in the North Fiji Basin (SW Pacific). The oceanic accretion in the North Fiji Basin (NFB) is characterised by a double spreading system (Auzende et al., 1994) with one spreading axis located in the median part of the basin (Central Spreading Ridge, CSR) and the second one located immediately west of the Fiji platform (West Fiji Ridge, WFR).

One aim of the HYFIFLUX cruise was the detailed mapping of the area between the previously mapped part of the West Fiji Ridge (*R/V Jean Charcot*), and the North Fiji Fracture Zone (NFFZ), using the Hydrosweep multibeam system with a swath width of two times the water depth. The other objective was the detailed mapping and sampling of the active and inactive hydrothermal sites located at the northern tip of the N15° segment of the Central Spreading Ridge. For this purpose the *R/V Sonne* was equipped with a video-photo deep tow system (EXPLOS), and various sampling tools such as TV Grab, multipiston corer, water sampling multiprobe, etc. The TV Grab is a rock sampling system similar to a giant pair of "sugar tongs" equipped with a TV camera attached at its middle. This camera allows to precisely identify and to select the sampling sites.

Results of HYFIFLUX cruise.

Mapping of the junction of the West Fiji Ridge with the North Fiji Fracture Zone

During the HYFIFLUX Cruise, complete multi-beam coverage of the WFR was obtained from 17°10'S up to its junction with the NFFZ. The 3D view map in Figure 1 shows the general bathymetry and structure of the area. Two principal domains can be identified: the spreading zone and the junction zone between the WFR and the NFFZ.

The spreading zone in this area is characterised by two axial segments. From 17°10'S to 16°51'S the spreading zone shows a deep graben with depths ranging from 3400 to 3100 m with a fairly uniform width of 4500-5000 m. It is bounded by steep walls from 3100 to 2800 m depth. In its southern part from 17°S to 17°10'S the graben deepens towards its axis. Between 16°51'S and 17°S the graben is divided in two symmetrical grabens by an axial dome 100 to 200 m high and 2 km wide which has been explored by deep tow profiling (see below). At 16°51'S a transverse fault crosses the whole area and offsets the oceanic crust structures indicating a left-lateral strike-slip motion (Fig. 1). Only the western wall of the spreading axis is unaffected by this transverse faulting. This allows us to conclude that the structure of the western wall is more recent than the strike-slip motion. North of the fault the axial graben narrows to 2.5 km width and has a more complex structure with asymmetric ridges and depressions distributed along the axis.

The junction zone between the WFR and the NFFZ is characterised by the curvature of all the structures. Towards the east the spreading axis graben abuts in a deep (more than 4000 m), wide (about 10 km) elongated E-W trending depression. To the west, the spreading axis is bound by an elongate E-W trending massif which rises to less than 2000 m depth; it is 10 km wide. To the north the area is limited by a steep EW scarp about 1000 m high. These different features constitute the junction between the WFR and the NFFZ. This junction could be interpreted as a RFF triple junction. The curvature of the spreading axis towards the east confirms the left-lateral motion of the NFFZ previously demonstrated (Falvey, 1978; Brocher and Holmes, 1985; Auzende et al., 1986; among others).

Deep towed survey of the West Fiji Ridge

Four deep towed EXPLOS runs were carried out during the HYFIFLUX cruise in an area centered at 16°55'S and 176°07'E, on both sides and on the top of the axial ridge. The axial ridge is discontinuous, 100-200 m high and 2 km wide, located in the central part of the main

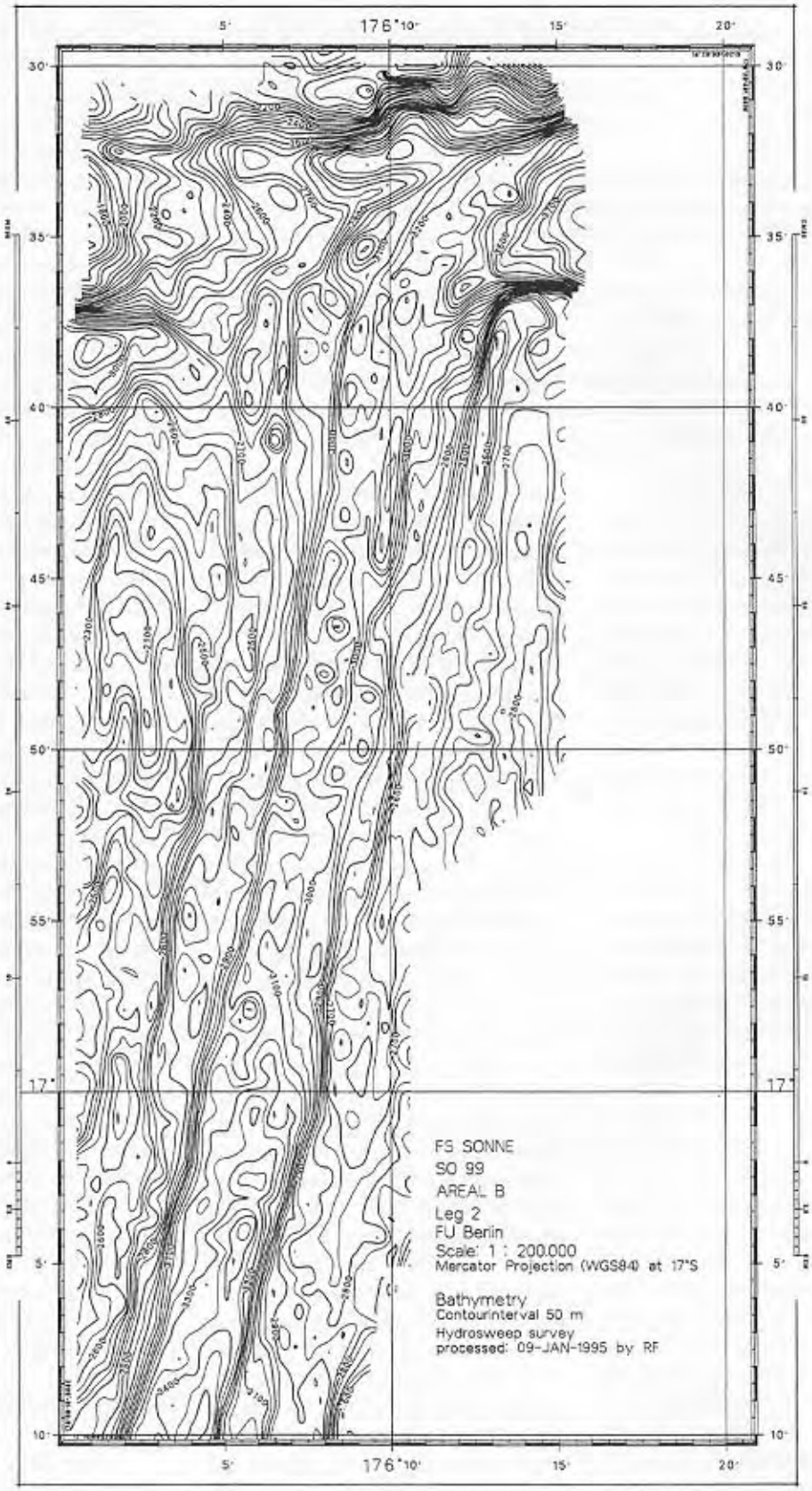

Figure 1 Bathymetric map of the northern part of the West Fifi Ridge and its junction with the Noth Fiji fracture zone; the junction is interpreted as an RFF triple junction. At 16°51'S a transverse fault crosses the whole area and offsets the oceanic crustal structures left laterally. Contour interval 50 m.

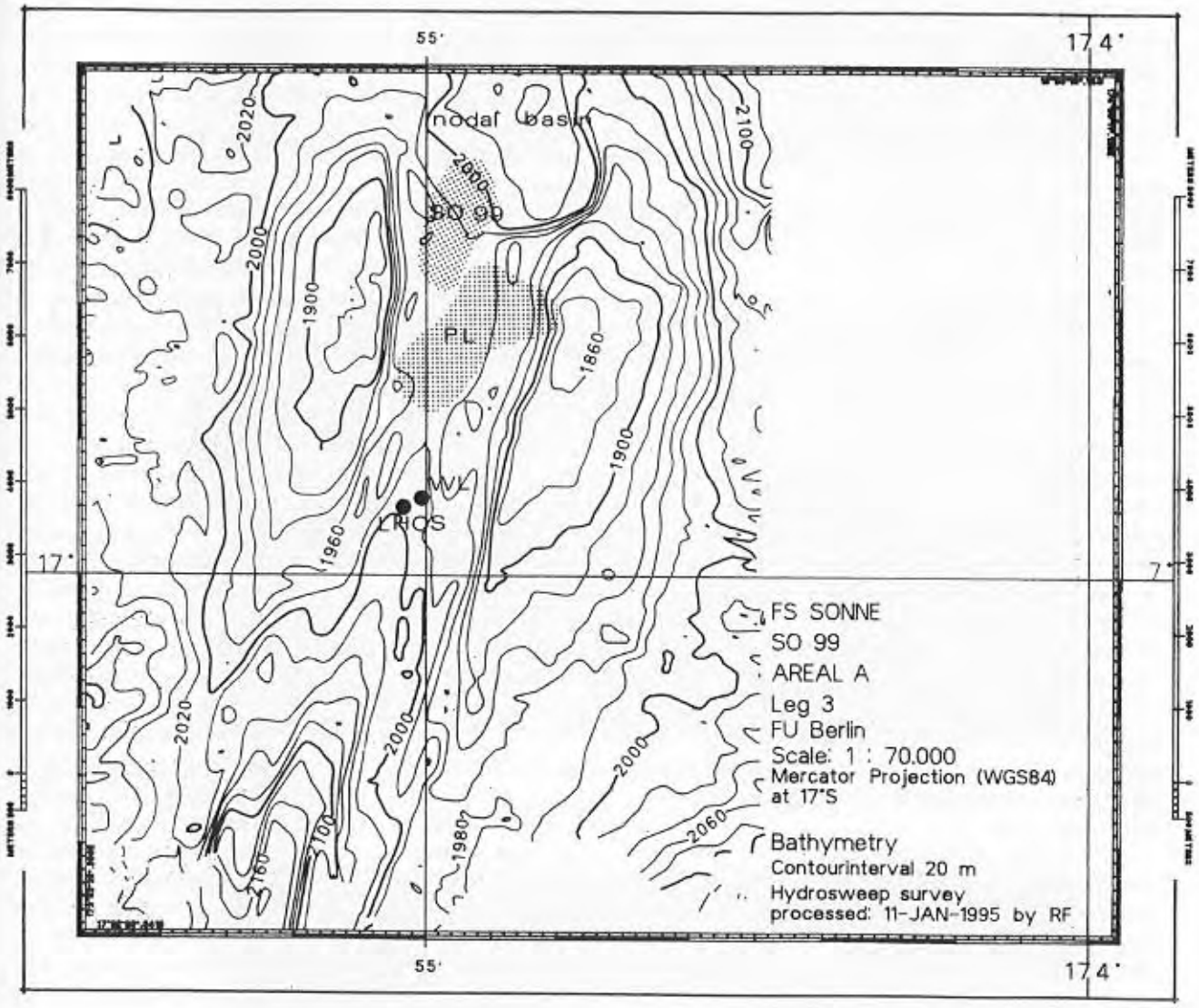

Figure 2 Bathymetric map of the northern part of the Central Fiji Ridge (N15° Segment) with the location of the new SO 99 field, Père Lachaise, the Whitte Lady and the LHOS hydrothermal sites. The SO 99 field is lacated immediately south of the round nodal basin of the triple point. Contour interval 20 m.

WFR graben, and bound by two symmetrical depressions. The deep tow surveys confirm that this part of the WFR is magmatically and tectonically active. The sea floor is covered by glassy basaltic pillows and tubes. On the top of the axial ridge and in the deepest part of the lateral depressions the pillows are covered by a thin sedimentary film, the thickness of which does not exceed 1 or 2 cm. In its middle part the axial ridge is cut by a graben, a few tens of meters wide, few meters deep, in which the lava is particularly fresh. The axial ridge is bound by active steep normal faults cutting pillow and tube lavas. At the foot of these faults large amounts of talus were observed and sampled by TV Grab.

No direct evidence of hydrothermal activity or deposits was detected during deep tow runs. The only indication of possible hydrothermal activity is given by temperature anomalies recorded on the deep tow tracks, along the eastern fault bounding of the axial ridge. Crossing this fault the temperature which was on average 2.084°C increased up to 2.131°C. This observation was made at two different places both located on the fault suggesting that at least low temperature waters are percolating through the fault bounding axial ridge.

Hydrothermal activity at the Central Spreading Ridge.

The first evidence of hydrothermal activity in the North Fiji Basin was the methane and manganese anomalies measured in the waters sampled during the SEAPSO III cruise aboard the *R/V Jean Charcot* (Auzende et al., 1986, 1988). Following this cruise other investigators obtained data confirming this activity (Craig et al., 1987; Grimaud et al., 1991, Ishibashi et al., 1994). The active White Lady hydrothermal site (Fig. 2) was discovered and sampled during the Starmer Nautile cruise (Auzende et al., 1991). The sulfides of the White Lady mound and Père Lachaise site (Fig. 2) were sampled during different cruises of the Starmer French-Japanese joint project and also by the Sonne 66 cruise. They were thoroughly studied by various investigators resulting in a large body of knowledge concerning the processes involved in their emplacement (Bendel, 1993; Halbach et al., 1991; Bendel et al., 1993)

The previously explored hydrothermally active sites on the NFB Central Spreading Ridge are probably representative of only a part of the total hydrothermal activity. The hydrocasts taken all along the ridge axis during the Starmer project suggest widespread hydrothermal activity with indications that it may, in some places, be very strong but unstable.

One of the main characteristics of the NFB ridge axis hydrothermal waters sampled by Nautile and Shinkai 6500 at the White Lady site, is their low salinity, which suggests that the fluids have undergone phase separation by boiling (Grimaud et al., 1991; Ishibashi et al., 1994). Such a phase separation would result in the formation of one vapour-like phase with low salinity and one liquid-like phase with high salinity (brine). Dissolved metal-species will be depleted in the vapor but phase separation will not significantly modify the elemental ratios as observed in the White Lady waters. The NFB hydrothermal waters could result from three-component mixing including normal seawater, low-salinity fluid from condensed vapor and brine.

EXPLOS survey of the Sonne 99 field

During the HYFIFLUX cruise 12 deep tow (EXPLOS) profiles were carried out northwest and west of the Père Lachaise area (between 16°58'S and 16°55'S). They confirm the existence of a 2 km wide graben opening to the north into a circular basin, 2100 m deep and 5 km in diameter which can be interpreted as a nodal basin marking the 16°50'S Triple Junction (Lafoy et al., 1990). The graben contains intensely fractured and fissured lava tubes, pillows and lakes near its axis. The principal observed trend of faulting is N015°E, which is parallel to the trend of the segment on which the area is located. Trends of N160°E and N045°E were also observed. The EXPLOS exploration allowed us to define the limits of the Père Lachaise fossil hydrothermal field previously explored by Nautile (Bendel, 1993). To the west and northwest of Père Lachaise, a new, very extensive hydrothermal field was discovered between 16°58'S and 16°57'S (SONNE 99 field; Fig. 2). It is an elongated deposit, 500 m wide and about 600 m long, with numerous fossil chimneys and several active chimneys (Fig 3) on the top of several mounds which reach heights of up to 6 m high. The chimneys are mostly located on the slopes or near the foot of the graben walls. Structurally the field is separated from the Père Lachaise site by an E-W to SW-NE trending smooth saddle and bound on its southern side by a normal fault, and to the north by the round nodal basin of the triple point. Another distinctive feature of the Père Lachaise site is the freshness and morphology of the lavas. In the SONNE 99 field the lava seems to be younger than that found at Père Lachaise. Also, there are many recent lava flows and scoriated lava instead of pillows and tubes.

A temperature anomaly was detected by the thermal probe installed at the EXPLOS-sledge, on the western edge of the deposit. In the same area, gastropods tests were observed concentrated at the foot of a large chimney. From video and photo observations they appear to be similar to those sampled by Nautile at the foot of White Lady site (Desbruyères et al., 1994). The highest temperature elevation (+0.35°C, measured about 3.5 m above the seafloor) and several weaker temperature anomalies as well as the presence of gastropods tests suggest that present-day, probably low temperature hydrothermalism exists in this area. The fluids emitted in this field are always translucent.

Rock, sulfide and water sampling in the Sonne 99 field

Nine TV Grab stations samples were obtained in the Sonne 99 field. A collection of volcanic rocks and massive sulfides was obtained at these stations. Overall, volcanic rocks sampled in this area are essentially aphyric basalts with extremely fresh glasses. They are dense with consistent grain size and no phenochrysts. While slight hydrothermal alteration of the basalts is observed in the White Lady and Père Lachaise sites, no macroscopically visible alteration was detected in the

Figure 3 Bottom photograph taken by the EXPLOS sledge of the SO 99 field showing the top view of a chimney structure. The chimney is about 3 m high. Remnents of hydrothermal fauna are still visable at its top. The scale weight is 25 cm long.

Figure 4 Bottom photograph taken by the EXPLOS sledge of the LHOS site showing a mussel bed (*Bathymodiolus*) partially covered by bacterial mats. Several gallateids (*Munidopsis*) may be observed towards the left of the photo. The scale weight is 25 cm long.

Figure 5 Bottom photograph taken by the EXPLOS sledge at the LHOS site: a large bed with numerous gastropods (*Alviniconcha hessleri*) and some mussels (*Bathymodiolus*) are observed. The gastropods are covered by bacterial mats. Some gallatheids are also observed. Small colonies of sessile barnacles (*Neolepas*) along the edges of the basaltic blocks are observed. The scale weight is 25 cm long.

Sonne 99 field. Most basalts from the N15° segment are depleted in LIL elements and have low trace element concentrations, for example, of Sr, Rb, Zr and Ba, which is characteristic of depleted N-MORB. However, basalts collected from immediately south of the triple junction show geochemical signatures transitional towards E-MORB or OIB (Eissen et al., 1994; Nohare et al., 1995). The basalt samples from the SO 99 field show a similar geochemical trend and are significantly enriched in K_2O, TiO_2, Sr, Rb, Zr, Nb and Ba (shipboard XRF-analyses data: K_2O: ~1.1 %, TiO_2: ~2.1 %; Sr: ~400 ppm ; Rb: ~29 ppm; Zr: ~210 ppm; Nb: ~44 ppm; Ba: ~270 ppm). The same samples are depleted in Cu (70-80 ppm) whereas the N-MORB samples have Cu concentrations of 140-150 ppm.

The sediment coring performed on- and off-axis, all suggest that the sedimentation in the area is very low. Cores taken in the symmetrical off-axis basins, where the age of the crust is supposed to be about 1.2 Ma from magnetic anomalies interpretation, give sedimentation rates ranging from 0.3 cm/1000 yr to up to 0.9 cm/1000 yr. Closer to the axis the sedimentation rates increase to up to more than 1 cm/1000 yr. This increase could be related to the effect of hydrothermal precipitates (Dekov and Kupsov, 1994). Most of the sulfides which were recovered (more than 1000 kg all told) were pieces of chimneys. Some were massive, consisting mainly of markasite and sphalerite. The Fe-sulfides are often intergrown with mm- to cm-sized anhydrite grains. Large amounts of well crystallized wurzite-rich areas are covered by smithsonite. Underneath a manganese crust of 2-3 mm thickness a yellow mineral was identified as greenockite. Smithsonite and greenockite are considered to be late-stage hydrothermal products. Another type of mineral assemblage is a highly altered basalt breccia (mm- to cm-sized fragments) which is cemented by pyrite, markasite and sphalerite. Frequent barite mineralisation reflects probably the enriched Ba-contents of the underlying basalts. Gypsum as well as zeolite crystals appear as last stage precipitates. Copper mineralisation which is abundant in the Père Lachaise field was not as frequently observed in SO 99 field sulphide samples. Chalcopyrite was typically observed as mm-thick fissure fillings in the inner part of the of the chimney fragments where the pyrite is strongly recrystallized. The alteration and weathering of the ores is less pronounced than in the Père Lachaise field.

Biological observations in the SO 99 field and at the LHOS site

The principal objective of the biological investigation to map the animal communities by the video-controlled EXPLOS deep-towed system. The first location investigated in detail was the Sonne 99 field in the northern part of the central graben system. A preliminary analysis of the fauna on board showed that most of the animals are not strictly related to the hydrothermal activity. However, suspension feeders (gorgonarian, crinoids, sponges) were found to be more abundant in the areas where the geological observations indicted were still slightly active. Of special interest is a euplectellid sponge, described by Desbruyères et al. (1994) as clustering at the outskirts of active vents in this basin. In one instance a galatheid of the genus *Munidopsis* was seen in such an area. Thus, a certain activity level can be confirmed for this area. The detailed analysis of the seafloor slides will allow better characterisation of individual areas. Some biological samples were obtained by picking up selected pieces of substrate with the TV-grab. Some of the dominant organisms as Crinoids, Orphiurids and Gorgonarians were collected and will facilitate the interpretation of the EXPLOS images. The second area was located in the highly hydrothermally active LHOS-field which yielded a species composition like the one described by Desbruyères et al. (1994). Very patchy occurrences of the dominant species were observed. *Bathymodiolus, Neolepas, Munidopsis, Alviniconcha* and *Alvinellides* were common, but very often not in the same spot. The euplectellid sponge was regularly present at the outskirts of the vent field. At least three species of fish were observed at the vents or nearby. Again, a few samples were taken with the TV-controlled grab. In addition to the known species, an as yet unidentified clam was collected, which does not appear in any earlier reports of vent fauna. Samples were fixed for taxonomic analysis and tissues were preserved of all animals collected for various investigations, especially for examination of bacterial symbiosis.

Sediment material recovered was washed through sieves and fractions >5 mm were preserved for macrobenthos analysis. In addition, samples for Meiobenthos investigations were taken. The close co-operation between geologists and biologists will continue during laboratory study and evaluation of the samples and data.

One important issue to be addressed is detailed definition of the link between geochemical (inorganic) and biological (organic) processes. We also plan to carry out a further research cruise in the White Lady area to investigate in particular the fluid chemistry and microbiology.

References

de Alteris, G., E. Ruellan, J.M. Auzende, H. Ondréas, V. Bendel, E. Gracia-Mont, Y. Lagabrielle, P. Huchon and M. Tanahashi, Propagating rifts in the North Fiji Basin (Southwest Pacific), Geology, 21, 583-586, 1993.

Auzende, J.M., J.P. Eissen, J.P. Caprais, P. Gente, S. Gueneley, F. Harmegnies, Y. Lagabrielle, A. Lapouille, C. Lefèvre, P. Maillet, J.P. Mazé, H. Ondréas, A. Schaaf and R. Singh, Accrétion océanique dans la partie méridionale du bassin Nord-Fidjien : résultats préliminaires de la campagne océanographique SEAPSO III du *N.O. Jean Charcot* (décembre 1985), C.R. Acad. Sci. Paris, 303, 93-98, 1986.

Auzende, J.M., J.P. Eissen, Y. Lafoy, P. Gente and J.L. Charlou, Seafloor spreading in the North Fiji Basin (Southwest Pacific), Tectonophysics, 146, 317-351, 1988.

Auzende, J.M., T. Urabe, V. Bendel, C. Deplus, J.P. Eissen, D. Grimaud, P. Huchon, J. Ishibash, M. Joshima, Y. Lagabrielle, C.

Mével, J. Naka, E. Ruellan, T. Tanaka and M. Tanahashi, In situ geological and geochemical study of an active hydrothermal site on the North Fiji Basin Ridge, Mar. Geol., 98, 259-269, 1991.

Auzende, J.M., B. Pelletier and Y. Lafoy, Twin active spreading ridges in the North Fiji Basin (S.W. Pacific), Geology, 22, 63-66, 1994.

Bendel, V., Cadre géologique et composition des minéralisations hydrothermales en contexte arrière-arc : exemple de la dorsale du Bassin Nord Fidjien, Thèse Univ. Brest, France, 259 p, 1993.

Bendel, V., Y. Fouquet, J.M. Auzende, Y. Lagabrielle, D. Grimaud and T. Urabe, Metallogenesis at a triple junction system: the White Lady hydrothermal field (North Fiji Back-Arc Basin, SW Pacific), Economical Geology, 88, 2237-2249, 1993.

Brocher, T.M., and R. Holmes, The marine geology of sedimentary basins south of Viti Levu, Fiji, in T.M. Brocher, (ed), Investigations of the Northern Melanesian Borderland, Circum- Pacific Council for Energy and Mineral Resources, Earth Science Series, 3, Houston, Texas, 123-138, 1985.

Chase, C.G., Tectonic history of the Fiji Plateau, Geol. Soc. Am. Bull., 82, 3087-3110, 1971.

Desbruyères D., A-M. Alayse-Danet, S. Ohta and the Scientific parties of Biolau and Starmer cruises, Deep-sea hydrothermal communities in the Southwestern Pacific back-arc basins (the North Fiji and Lau Basins): composition, microdistribution and food web, in: the North Fiji Basin (SW Pacific), J.M. Auzende and T. Urabe (eds), Marine Geology, STARMER Special Issue, 116, 1/2, 227-242, 1994.

Eissen, J.-P., M. Nohara, J. Cotten and K. Hirose, North Fiji Basin basalts and their magma sources: Part I. Incompatible element constrains. Marine Geology, 116, 153-178, 1994.

Falvey, D.A., Analysis of paleomagnetic data from the New Hebrides, Bull. Aust. Soc. Explor. Geophys., 9, 3, 117-123, 1978.

Grimaud, D., J.I. Ishibashi, Y. Lagabrielle, J.M. Auzende and T. Urabe, Chemistry of hydrothermal fluids from the 17°S active site on the North Fiji Basin ridge (SW Pacific), Chemical Geology, 93, 209-218, 1991.

Halbach, P., A. Koschinsky, P. Dreßen, B. Pracejus and S. Bubilete, Geowissenschaftliche Untersuchungen und lagerstättenkundliche Bewertung der Erzkrusten des zentralen Pazifiks südlich des Äquators (SO 66); Hydrothermale Mineralisationen aus Areal x (White Lady area, NFB).- BMFT- Bericht, Clausthal- Zellerfeld, 176- 182, 1981.

Hamburger, M.W. and B.L. Isacks, Diffuse back-arc deformation in the Southwestern Pacific, Nature, 332, 599-604, 1988.

Ishibashi, J., D. Grimaud, Y. Nojiri, J.M. Auzende and T. Urabe, Fluctuation of chemical compositions of the phase-separated hydrothermal fluid from the North Fiji Basin, in the North Fiji Basin (SW Pacific), J.M. Auzende and T. Urabe (eds), Marine Geology, STARMER Special Issue, 1994.

Lafoy, Y., J.M. Auzende, E. Ruellan, P. Huchon and E. Honza, The 16°40'S Triple Junction in the North Fiji Basin (SW Pacific), Mar. Geophys. Res., 12, 285-296, 1990.

Louat, R. and B. Pelletier, Seismotectonic and present-day relative plate motions in the New Hebrides-North Fiji Basin region, Tectonophysics, 167, 41-55, 1989.

Maillet, P., J.P. Eissen, A. Lapouille, M. Monzier, V. Balcivanualal, J. Butscher, F. Gallois and M. Lardy, La dorsale active du bassin Nord-Fidjien entre 20°S et 20°53'S : signature magnétique et morphologique, C.R. Acad. Sci. Paris, 302, II, 135-140, 1986.

Nohara, M., K. Hirose, J.-P. Eissen, T. Urabe and M. Joshima, The North Fiji Basin basalts and their magma sources: Part II. Sr-Nd isotopic and trace element constrains, Marine Geology 116, 179- 195, 1994.

Pelletier, B., and R. Louat, Mouvement relatif des plaques dans le Sud-Ouest Pacifique, C.R. Acad. Sci. Paris, 308, 123-130, 1989.

The InterRidge Office is currently accepting submittal of articles for the next issue of *InterRidge News* to be published in October 1995.

Ridge crest researchers are encouraged to submit their findings as short articles (1-4 printed pages with up to 3 figures).

Appropriate topics include:

- preliminary results of ridge crest cruises, particularly involving multi-national co-operation
- technical or engineering developments capable of enhancing ridge crest investigations.

Submission:

- Prefered submission method/format is as via the Internet as an attached RTF file.
- Please check this issue for reference style.

Articles must arrive in the InterRidge Office no later than 30 September 1995.