CTD observations to search for hydrothermal activity on the Southwest Indian Ridge and the Central Indian Ridge just north of the Rodriguez Triple Junction: the *Yokosuka/Shinkai* MODE'98 Leg 3 INDOYO cruise

Yoshiki SOHRIN *1 Toshitaka GAMO *2
the Shipboard Science Party of the INDOYO *3

Reconnaissances of hydrothermal activity were carried out using the submersible *Shinkai 6500* at 31°05'S, 59°00'E in the West Box and at 27°54'S, 64°29'E in the East Box on the Southwest Indian Ridge (SWIR) and at 25°19'S, 70°02'E in the off-axis area of the Central Indian Ridge (CIR) just north of the Rodriguez Triple Junction during the *Yokosuka/Shinkai* MODE'98 Leg 3 INDOYO cruise (September–October, 1998) for the purpose of finding the first active venting site in the Indian Ocean. Although seven dives failed in locating the active venting site, strong anomalies of light transmission (up to 0.5%) were found at 2200–2450 m depth during the dives in the off-axis area of the CIR, suggesting that the hydrothermalism was active as well as in 1993 when hydrothermal plumes had been discovered in this area. In addition, temperature anomalies were observed on the bottom in the off-axis area of the CIR and the East Box. The strongest anomalies of ~0.1°C were observed at the axial volcanic ridge Mt. Jourdanne (27°50.97'S, 63°56.15'E) in the East Box, where the first extinct chimneys were found in the Indian Ocean.

Key words : South West Indian Ridge, Central Indian Ridge, Rodriguez Triple Junction, hydrothermal activity, transmission anomalies, temperature anomalies

---

*1 Faculty of Technology, Kanazawa University
*2 Ocean Research Institute, University of Tokyo
*3 H. Fujimoto, S. Ohta & T. Yama-ashi (Ocean Research Institute, University of Tokyo); M. Cannat & C. Mével (Laboratoire de Pétrologie, CNRS-UPMC); K. Fujioka (Deep Sea Research Department, JAMSTEC); C. German & L. Parson (Southampton Oceanography Centre.); U. Münch (Freie Universität Berlin); M. Oyaizu (Nippon Marine Enterprise); R. Searle (Department of Geological Sciences, University of Durham)

1. INTRODUCTION

Although twenty years have passed since the first discovery of hydrothermal activity on the ocean floor, there have been few studies in the Indian Ocean. The Indian Ocean basin is subdivided by the Southwest Indian Ridge (SWIR), the Central Indian Ridge (CIR), and the Southeast Indian Ridge (SEIR), which meet at the Rodriguez Triple Junction (RTJ). These ridges are unique, since their spreading rate ranges from very slow to intermediate [1] and they are the sole migration pathway between the diverse vent fauna of the Atlantic and Pacific Oceans[2].

Herzig and Plüger [3] and Plüger et al. [4] showed the existence of hydrothermal activity at 21.5°S; 23.0°S, and 24.0°S (SONNE Hydrothermal Plume Site) along the CIR from anomalous CH_4 and Mn profiles. Jean-Baptiste et al. [5] reported hydrothermal anomalies of $\delta\,^3He$ and Mn at 19°29'S on the CIR. In the area close to the RTJ, water column anomalies of light transmission, Mn, Fe, Al, and CH_4 were searched during the KH-93-3 cruise of RV *Hakuho Maru* (Ocean Research Institute, The University of Tokyo) in July–August 1993 [6]. An active zone was found on the CIR (25°18–20'S) about 12 miles north of the RTJ, where significant hydrothermal plumes were observed at 2200–2400 m depth. Intensive tow-yo observations using a CTD rosette multi-sampling system equipped with a transmissometer revealed that the plumes show temporal as well as spatial variations. Discrete water samples within the plumes were enriched in Mn, Fe, and CH_4, with maximum concentrations of 9.8 nM, 40.2 nM, and 3.3 nM, respectively. Judging the spatial and chemical characteristics of the plumes, the authors concluded that the hydrothermal plumes were discharged from the eastern off-axis wall or axial high at a depth of < 2800 m, several miles eastward from the center of the CIR rift valley. Scheirer et al. [7] found six sites having optical back-scatter anomalies indicative of hydrothermal plumes along the SEIR (37°43'–42°29'S). At one site, they also found near bottom temperature anomalies of ~0.1°C and recovered a vent-specific barnacle. During the FUJI (French-UK-Japanese InterRidge) cruise aboard RV *Marion Dufresne*, October 1997, first evidence for hydrothermal activity along the SWIR was located from mid-water suspended particulate plumes [8]. Six optical back-scatter instruments were attached to the cable of a deep-tow sidescan sonar instrument (TOBI), at 50 m intervals above and below the deep-tow vehicle, to obtain a 300 m vertical swath of hydrothermal plume information through the water column. Using this approach, evidence of hydrothermal plumes was detected at six locations within two 200-km-long sections of the SWIR.

The *Yokosuka/Shinkai* MODE'98 Leg 3 INDOYO cruise was conducted from September to October 1998 [9], of which major objective was to locate active hydrothermal fields on the SWIR and the CIR just north of the RTJ. We obtained the data of seawater characteristics throughout the dives of *Shinkai 6500*, using a CTD with transmissometer and H_2S sensor. Salinity, potential temperature, potential density, light transmission and the concentration of H_2S were measured. Here we report the results of the *in situ* measurements.

2. SURVEY AREA

Among 14 dives (# 444–457) conducted during the INDOYO cruise, seven dives were dedicated to reconnaissance of hydrothermal activity in three areas: at 31°05'S, 59°00'E in the West Box and at 27°54'S, 64°29'E in the East Box on the SWIR and at 25°19'S, 70°02'E in the off-axis area of the CIR just north of the RTJ [9].

Hydrothermal vents at mid-ocean ridges emit hot and anoxic fluids which mix turbulently with ambient sea water as they rise from the sea floor, precipitating various sulphide and oxide phases, until some level of neutral buoyancy is attained [10]. Resultant plumes are dispersed along isopycnal surfaces. During the FUJI survey, strong back-scatter anomalies were observed in Segment 10 near 27°55'S, 64°30'W at a depth of 3900–4000 m [8] in the East Box. Assuming heights of rise of neutrally buoyant plumes to be similar to those of the North Atlantic Ocean, a depth of venting was estimated to be no greater than 4300–4500 m. Of four potential topographic highs (< 4400 m depth), dives 448 and 449 were focused on a central axial volcanic ridge. The strongest back-scatter anomaly during the FUJI cruise was observed in the West Box[8]. The plume occurred at a depth of 4100 m, with maximum anomalies located in the non-transform discontinuity between Segments 16 and 17 (31°05'S, 59°01'E). Dives 451, 452, and 453 targeted at the topographic highs (< 4400 m depth) on an axial volcanic ridge and the southern rift-valley wall.

In the area of the CIR just north of the RTJ, dives 456 and 457 were focused on a spur extending to the NE from a ridge summit at 25°19'S, 70°03'E (Figure 1), where the densest portion of hydrothermal plumes observed during the KH-93-3 cruise in terms of light transmission anomaly and CH_4/Mn ratio [6]. Since the center of the plumes observed in 1993 was situated at a depth between 2200 and 2300 m, the top of the spur around 2450 m was a reasonable candidate of the source.

The other seven dives were conducted to characterize the accretionary processes in the ultra-slow spreading environment of the SWIR. They were concentrated on Segment 11 (~27.9°S, ~63.8°E) in the East Box, two on the axial volcanic ridge Mt. Jourdanne, three on a "megamullion", and two in the non-transform discontinuity.

3. METHODS

The CTD with a transmissometer and a H_2S sensor was mounted in the left-side sampling basket of *Shinkai 6500*.

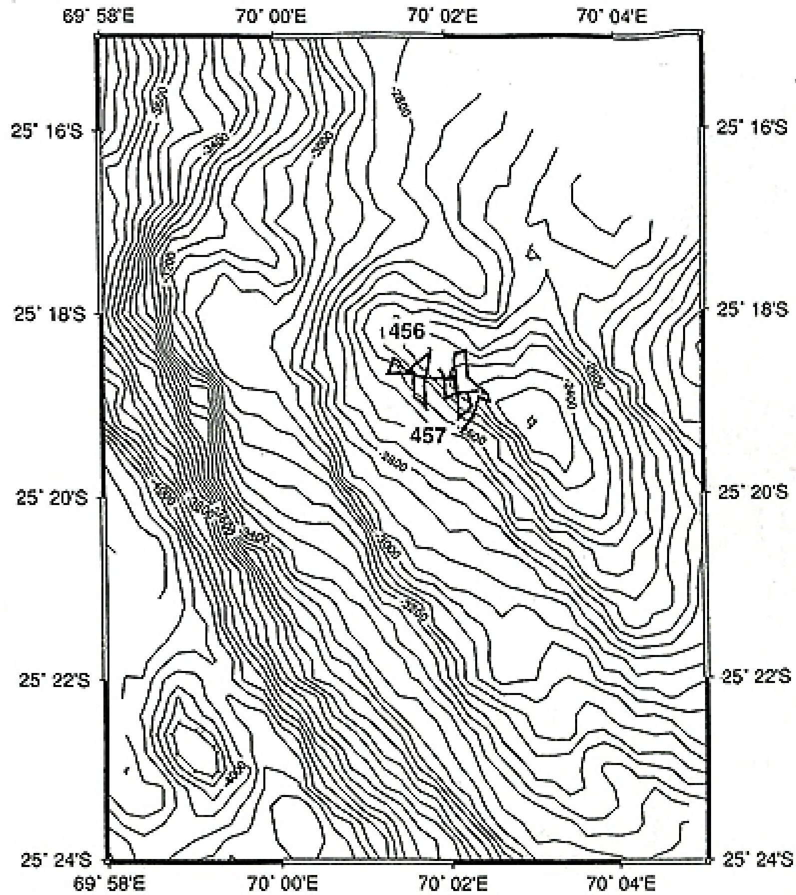

Fig. 1 Dive sites of *Shinkai 6500* in the off-axis area of the CIR just north of the RTJ during the INDOYO cruise.

The data were recorded in a solid-state memory inside the CTD pressure housing throughout the dive and transferred to a computer after the dive followed by processing. The CTD used was a SEALOGGER CTD SBE 25-02 (Sea-Bird Electronics). The conductivity sensor was a SBE 4C 6800 m. The temperature sensor was a SBE 3F 6800 m. The pressure sensor was a SBE 29. The transmissometer used was a WETLabs C-Star 25 cm for the dive 444 and a SeaTech-25 cm Type (5000 m) for the dives 449–457. The H_2S sensor was an amperometric H_2S microsensor (AMT Analysenmesstechnik), which responded to dissolved molecular H_2S. The computer was a VAIO PCG-733_A (SONY).

The sensors of the CTD were calibrated by Sea-Bird Electronics before the cruise. The outputs of the Sea Tech transmissometer and the H_2S sensor were recorded in the unit of mV, owing to lack of parameters for calibration.

4. RESULTS

4.1 Signals of hydrothermal plumes

The dives 448 and 449 in the East Box, 451, 452 and 453 in the West Box, and 456 and 457 in the off-axis area just north of the RTJ were conducted to search for the first site of active hydrothermal venting in the Indian Ocean. Vertical profiles of light transmission, potential temperature and the output of H_2S sensor were examined to find the signs of hydrothermal plumes. Suspension of sediment particles was trapped in the basket and prevented meaningful collection of transmission data during the upcast of the dive 452. The profiles of transmission were different between downcast and upcast for each dive, and transmission decreased slightly with depth. This may have been caused by hysteresis of the transmissometer. The fact that transmission decreased below 3900 m may have been due to resuspension of bottom sediments. Distinct transmission anomalies (up to 0.5%) were detected at 2200–2450 m depth during the dives 456 and 457 (Figure 2). These anomalies probably indicate hydrothermal plumes. Potential temperature and the output of the H_2S sensor did not show any significant anomalies. No significant anomaly was observed in the water column at the other dive sites.

4.2 Bottom data

Light transmission within a few meters above the bottom is expected to serve as an indicator of hydrothermal activity. Unfortunately, it was hard to interpret the data because resuspension of sediments caused by the submersible made strong spike noises. The output of the H_2S sensor was less

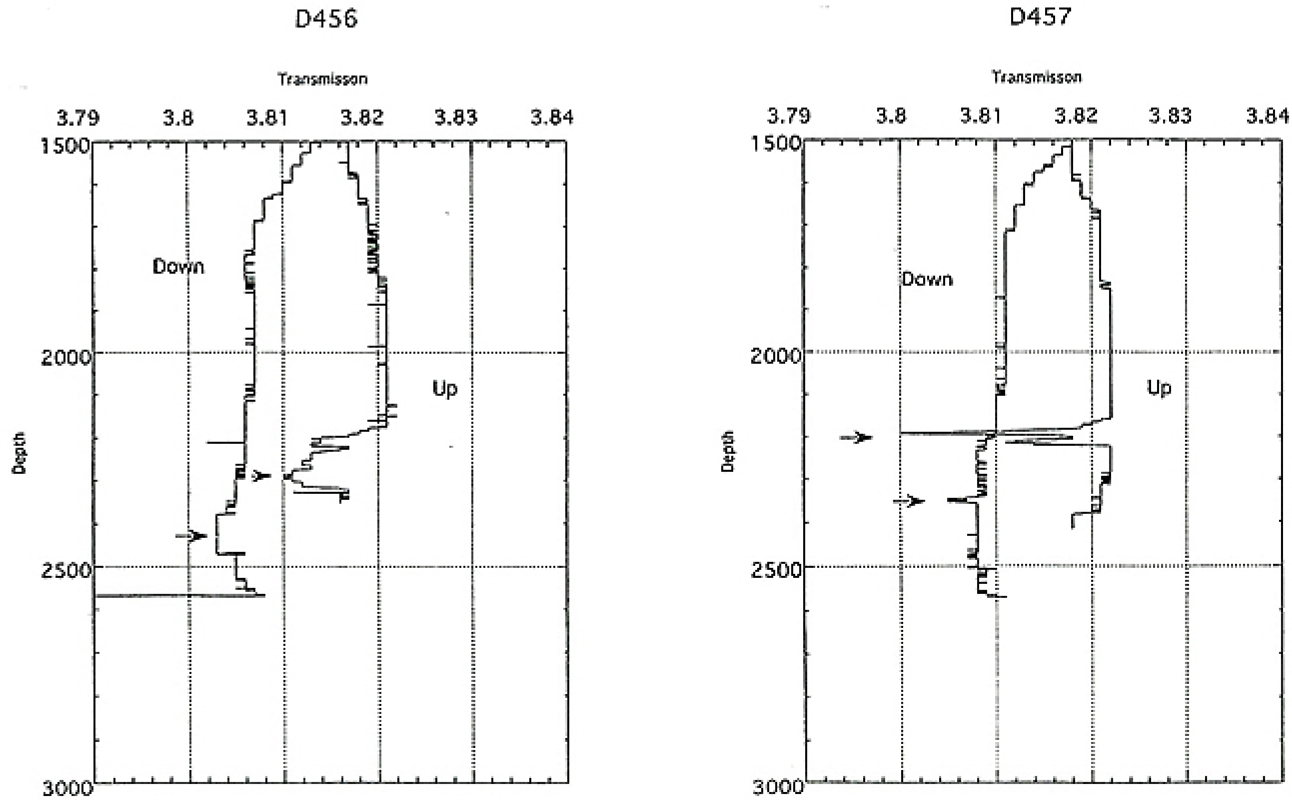

Fig. 2 Vertical profiles of light transmission during the dives 456 and 457 in the off-axis area just north of the RTJ.

than the detection limit for all dives. Salinity also showed no meaningful variation.

The variation of potential temperature on the bottom was usually less than 0.03°C below 3500 m depth. This was also true of the hydrothermal targets on the SWIR. Large anomalies of temperature compared to the background were observed at some dive sites. The temperature anomalies were up to 0.05°C at FUJI Dome (dives 444 and 450; 28°02'S, 63°46'E) and the CIR hydrothermal target (dives 456 and 457; Figure 3). Strongest anomalies of ~0.1°C were observed at Mt. Jourdanne (dives 446 and 454; 27°51'S, 63°56'E; Figure 4).

5. DISCUSSION

5.1 Hydrothermal targets on the SWIR

No evidence for active hydrothermal venting was observed during the dives 448 and 449 in Segment 10 in the East Box and the dives 451–453 in Segments 16/17 in the West Box. The transmission anomalies (hydrothermal plume) detected during the FUJI cruise [8] were found to have completely disappeared.

5.2 Mt. Jourdanne, an axial volcanic ridge of the SWIR

Inactive hydrothermal deposits were discovered serendipitously on the NE slope close to the summit of Mt. Jourdanne during the dive 446. Additional dive 454 was conducted to explore the graben area for active venting and to sample further hydrothermal precipitates. Several extinct hydrothermal sites were found within an area of ~0.5 km^2 at a water depth of 2941 m (27°50.97'S, 63°56.15'E) [9]. All of the extinct hydrothermal sites were related spatially either to the graben or to smaller fissures. Hydrothermal precipitates consisted of sulfide impregnated basalts, and massive sulfides dominated by pyrite, sulfates and oxides. Hydrothermal products occurred on the ocean floor as mounds with an average size of ~5 m^3 and small chimneys. Bottom temperature anomalies of ~0.1°C were detected nearby the extinct hydrothermal sites. On the other hand, there were no signs of hydrothermal plumes on the water column data of the CTD. Biological features of even relicts were not observed in the entire area of the summit of Mt. Jourdanne.

5.3 CIR just north of the RTJ

The two dives 456 and 457 made important progress in approaching hydrothermal active sites in this area, although the very point could not be reached by these missions. Dead heaps of two species of the giant white clams (*Calyptogena*) were found just on the landing site of the dive 456 [9]. The state of the shells strongly suggested that recent existence of chemosynthetic ecosystems characteristic of hydrothermal activity. The light transmission anomalies were commonly

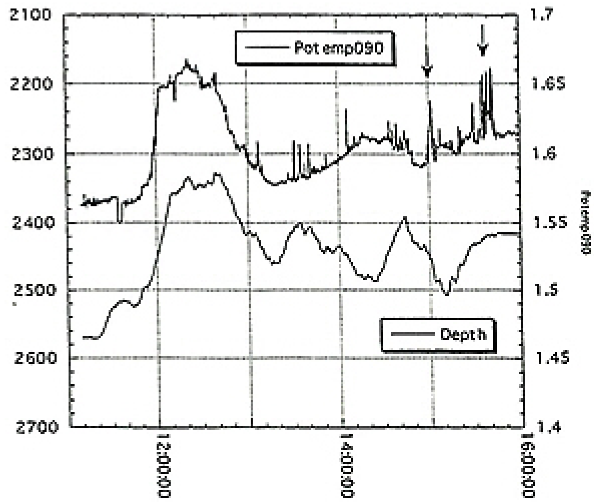

Fig. 3 Potential temperature and depth on the bottom during the dive 457 in the off-axis area just north of the RTJ.

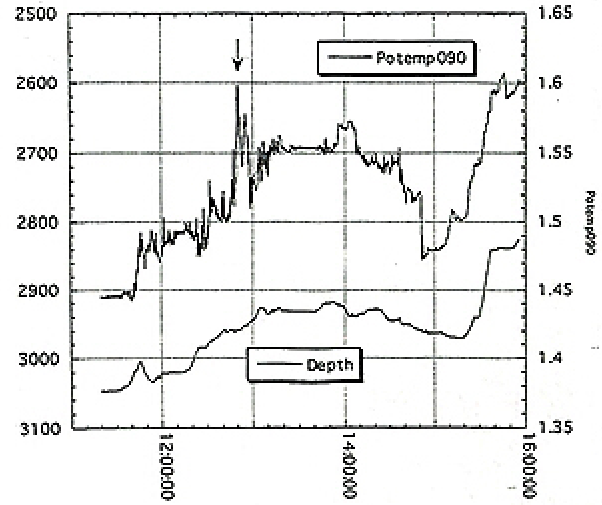

Fig. 4 Potential temperature and depth on the bottom during the dive 446 at Mt. Jourdanne.

observed during descending and ascending of *Shinkai 6500* for both dives. The anomalies appeared at depths of 2200–2400 m, almost the same depth as that observed during the *Hakuho Maru* cruise in 1993 [6]. This suggests that the transmission anomaly observed this time should be regarded as hydrothermal plumes. Hydrothermal activity may have continued for these five years. During the dive 457, transmission anomaly reached to 0.5% (at a depth of 2200 m) above the leaving point of the dive. This anomaly is about five times larger than that observed during the KH-93-3 cruise, which may imply that the survey area is much closer to a venting site. In addition, bottom temperature anomalies of ~0.05°C were detected at some locations during the both dives. These results strongly suggest the existence of hydrothermal activity nearby the survey area. It is desirable to continue the diving survey in near future in order to locate the very site of hydrothermal venting.

ACKNOWLEDGEMENTS

We thank K. Tamaki for providing us useful information. The operation team of DSV *Shinkai 6500* and the crew of RV *Yokosuka* are acknowledged for their skilful support. This study was partially supported by the grant-in-aid from the Ministry of Education, Sports, Science and Culture.

REFERENCES

1) C. DeMets, R.G. Gordon, D.F. Argus and S. Stein, " Current plate motions," Geophys. J. Int., **101**, 425–478, (1990).
2) V. Tunnicliffe and C.M.R. Fowler, "Influence of seafloor spreading on the global hydrothermal vent fauna," Nature, **379**, 531–533, (1996).
3) P.M. Herzig and W.L. Plüger, "Exploration for hydrothermal activity near the Rodriguez Triple Junction, Indian Ocean," Can. Mineral. **26**, 721–736, (1988).
4) W.L. Plüger, P.M. Herzig, K.P. Becker, G. Deissmann, D. Schops, J. Lange, A. Jenisch, S. Ladage, H.H. Richnow, T. Schulze and W. Michaelis, "Discovery of hydrothermal fields at the Central Indian Ridge," Mar. Min. **9**, 73–86, (1990).
5) P. Jean-Baptiste, F. Mantisi, H. Pauwells, D. Grimaud and P. Patriat, "Hydrothermal ^3He and manganese plumes at 19°29'S on the Central Indian Ridge," Geophys. Res. Lett. **19**, 1787–1790, (1992).
6) T. Gamo, E. Nakayama, K. Shitashima, K. Isshiki, H. Obata, K. Okamura, S. Kanayama, T. Oomori, T. Koizumi, S. Matsumoto and H. Hasumoto, "Hydrothermal plumes at the Rodriguez triple junction, Indian ridge," Earth Planet. Sci. Lett. **142**, 261–270, (1996).
7) D.S. Scheirer, E.T. Baker and K.T.M. Johnson, " Detection of hydrothermal plumes along the Southeast Indian Ridge near the Amsterdam-St. Paul Plateau," Geophys. Res. Lett. **25**, 97–100, (1998).
8) C.R. German, E.T. Baker, C. Mevel, K. Tamaki and the FUJI Science Team, "Hydrothermal activity along the southwest Indian ridge," Nature **395**, 490–493, (1998).
9) H. Fujimoto, M. Cannat, K. Fujioka, T. Gamo, C. German, C. Mevel, U. Munch, S. Ohta, M. Oyaizu, L. Parson, R. Searle, Y. Sohrin and T. Yama-ashi, " First submersible investigations of mid-ocean ridges in the Indian Ocean," InterRidge News **8**, 22–24, (1999).
10) J.E. Lupton, J.R. Delaney, H.P. Johnson and M.K. Tivey, "Entrainment and vertical transport of deep ocean water by buoyant hydrothermal plumes," Nature **316**, 621–623, (1985).

(Manuscript received 19 August 1999)