Geochemistry of phase-separated hydrothermal fluids of the North Fiji Basin, Southwest Pacific

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Abstract—The White Lady hydrothermal field located in the Central Ridge of the North Fiji Basin was the second example of a phase-separated hydrothermal system, described after the ASHES vent field at the Juan de Fuca Ridge. This discovery confirmed that the phase separation process during fluid circulation is a rather ubiquitous process in submarine hydrothermal systems at relatively shallow depth. The chemistry of venting fluids is characterized by low chlorinity, slight CO₂ enrichment, and depletion in iron. These features are quite similar to those of the vapor-rich fluids in the ASHES vent field and indicate evidence that these hydrothermal systems have experienced subcritical boiling, phase segregation and metal sulfide precipitation beneath the seafloor. The original single-phase hydrothermal fluid prior to phase separation in the North Fiji Basin hydrothermal system is expected to have a common fluid chemistry to those from the mid-oceanic ridges. Isotopic compositions of gas species which are encompassed by the MORB range, are accordance with this similarity. Re-sampling of the White Lady chimney fluid confirmed no significant temporal change in the chemical composition during two years, suggesting that the phase-separation occurs in steady state. Around the active anhydrite chimneys, huge fossil sulfide chimneys widely distribute. This occurrence implies that the present boiling-stage hydrothermal activity replaced a more active non-boiling stage, with retreat of magmatic activity beneath the hydrothermal system.

INTRODUCTION

Recent investigations in the western Pacific region have discovered a number of hydrothermal systems on the seafloor. Hydrothermal systems are now revealed as not unique phenomenon to the mid-oceanic ridge system, but ubiquitous in active volcanic regions on the seafloor in various tectonic settings (ISHIBASHI and URABE, 1995).

The North Fiji Basin is an active, mature backarc basin located at the boundary between the Pacific and Indo-Australian plates (Fig. 1). The STARMER project under the framework of Japan-France-SOPAC cooperation investigated interdisciplinarily (geology, geochemistry, geophysics and biology) the spreading system of the North Fiji Basin (AUZENDE and URABE, 1994). During five years of the project (1987–1992), seven cruises were carried out; four of them (Kaiyo 87, Kaiyo 88, Kaiyo 89 and Yokosuka 90) were dedicated to surface-ship surveys, and the other three were diving cruises using the Nautilie (June–July 1989), the Shinkai
6500 (September–November 1991), and the Cyana (December 1991–January 1992).

Hydrothermal activity in the North Fiji Basin has been denoted by chemical anomalies detected in hydrothermal plumes during the PAPATUA expedition of 1986 (Craig et al., 1987), the SEAPSO III cruise of 1986 (Auzende et al., 1988), and the R/V Moana Wave cruise of 1987 (Sedwick et al., 1990). During the Kaiyo 87 and Kaiyo 88 cruise, several hydrothermal plumes including megaplume-like one were detected along the Central ridge (Nojiri et al., 1989). In addition, active hydrothermal sites were confirmed using a deep-tow TV camera system (Kaiyo 87 Shipboard Party, 1988; Momma et al., 1989; Auzende et al., 1990). During the first reconnaissance dive of the 1989 Nautili program, an anhydrite chimney vigorously venting transparent fluid of 285°C was discovered (Auzende et al., 1991; Urabe et al., 1990). This chimney was named “White Lady” and was selected as one of main targets of following dives. In 1991, two years later, Shinkai 6500 revisited this field and confirmed its steady activity (Auzende et al., 1992).

Hydrothermal fluids collected from the White Lady chimney have low chlorinity around half of seawater value, which indicates evidence for subcritical boiling during sub-seafloor hydrothermal circulation (Grimaud et al., 1991). This was the first example of the phase-separated hydrothermal systems in the backarc basins, and second in the world after the ASHES vent field, Juan de Fuca Ridge which was reported by Massoth et al. (1989). This paper summarizes geochemical studies of the phase-separated hydrothermal fluids collected from the Central ridge of the
North Fiji Basin, with a discussion on how phase-separation controls fluid chemistry.

GEOLOGICAL SETTING OF THE HYDROTHERMAL FIELD OF THE NORTH FIJI BASIN

The North Fiji Basin has experienced complex multi-stage tectonic history since its beginning of spreading at 10–12 Ma, and the present spreading activity has started since about 1 Ma along the Central ridge of 800 km long (e.g., MALAHOFF et al., 1982; AUZENDE et al., 1988; TANAHASHI et al., 1991; HUCHON et al., 1994). This spreading system can be divided into four first-order segments: northern (N160E), northern-central (N15E), southern-central (N5E) and southern offset (NS) segments (EISSEN et al., 1991) (see Fig. 1).

The Central ridge is located 150 to 500 km far from the present subduction of the New Hebrides Trench, and the Wadati-Benioff zone does not extend beneath it. Thus the present spreading activity should occur free from the subduction process. The Central ridge is comparable to mid-oceanic ridge systems in several features, such as size, bathymetric profiles, and morphologic variations (TANAHASHI et al., 1994; GRACIA et al., 1994). Petrological studies demonstrate dominant N-MORB feature of basalt samples, indicating a mature signature of the North Fiji Basin spreading activity (EISSEN et al., 1991). Influence of subduction contamination appeared in only a few samples, and this influence is attributed to the partial melting of a mantle source suffering from remnant subduction (EISSEN et al., 1991). On the other hand, some influence of co-existing Oceanic Island Basalt (OIB) components is recognized by co-variation of incompatible trace element abundance and Sr-Nd isotope systematics (EISSEN et al., 1994; NOHARA et al., 1994).

The White Lady chimney was found in the 2 km wide axial graben on a bathymetric rise (Fig. 2). This site, which was called “Station 4”, is located at the northern tip of the northern-central (N15E) segment and is adjacent to a ridge-ridge-flucture zone triple junction (AUZENDE et al., 1991). Hydrothermal activities in Station 4 distribute over a thinly sediment covered fresh sheet lava flow (BENDEL et al., 1993; GRACIA et al., 1994). Other anhydrite chimneys in the “STARMER II” area were found about 150 m southwest of the White Lady chimney (GRACIA et al., 1994; ISHIBASHI et al., 1994a). Dense hydrothermally-supported fauna of balanoid, black gastropods, hairy gastropods and mussels thrive around the active chimneys (DESBRUYERES et al., 1994).

The White Lady chimney consists exclusively of anhydrite and is developed on a 2 m high sulfide mound (BENDEL et al., 1993). For two years between the two diving cruises, the hydrothermal activity seems to have persisted in emanating fluid, in spite of the change in the shape of the chimney (AUZENDE et al., 1992). The highest measured temperature of the venting fluid was 285°C in 1989, which decreased to 265°C in 1991 (ISHIBASHI et al., 1994a). The active chimneys in the STARMER II area also consist of anhydrite and emanate transparent fluid. The fluid temperature measured at two chimneys, “Kaiyo” and “LHOS”, ranges from 230°C to 290°C. Extinct huge sulfide chimneys distribute widely in the same graben structure
Fig. 2. Bathymetric and morphostructural sketch of Station 4 (modified from GRACIA et al., 1994).

(GRACIA et al., 1994). The height of chimneys in the area “Pere Lachaise”, which is in the northern part of Station 4, reaches from 15 to 20 m. They imply that intense black smoker hydrothermal activity previously existed in the same graben (BENDEL et al., 1993; GRACIA et al., 1994).

PHASE SEPARATION PROCESS DURING SUB-SEAFLOOR HYDROTHERMAL FLUID CIRCULATION

Since the discovery of high-temperature fluid venting on the seafloor, it has been argued how phase separation proceeds in submarine hydrothermal systems. A
variety of evidence, especially wide chlorininity variation, is attributed to a fact which supports that venting fluid has experienced boiling during hydrothermal circulation. VON DAMM and BISCHOFF (1987) studied hydrothermal fluids from the Southern Juan de Fuca ridge and demonstrated high concentrations of chlorine and cations, which are beyond the possible range of deviation caused by fluid-rock interactions. They proposed a model of sub-seafloor mixing between hydrothermally evolved seawater and two phases (vapor and brine) produced during phase separation. Coexistence of vapor-rich and hypersaline fluid inclusions in vein quartz of sulfide-bearing greenstone breccia is considered as evidence for supercritical boiling beneath the mid-oceanic ridge (e.g., DELANEY et al., 1987).

BISCHOFF and ROSENBAUER (1984, 1985, 1988) investigated experimentally the phase relations of seawater and indicated that the two-phase boundary of seawater coincides with that of 3.2 wt% of NaCl in the H2O system (Fig. 3). When a fluid encounters the phase boundary at temperatures below the critical point, subcritical boiling forms a nearly pure water vapor phase from a saline liquid phase (brine). Until the boiling temperature approaches to within 10–15°C of the critical point, the vapor phase contains much less salt than the liquid phase. On the other hand, supercritical phase separation which occurs at temperatures higher than the critical point results in formation of a small amount of highly saline brine from a

![Fig. 3. Two-phase boundary curve for 3.2 wt% NaCl in H2O system (equivalent to seawater). Data from BISCHOFF and ROSENBAUER (1985). Each mark indicates P-T condition of fluid venting at the seafloor: closed triangle = North Fiji Basin, Station 4, White Lady (GRIMAUD et al., 1991); closed circle = Juan de Fuca Ridge, ASHES, Virgin Mound (BUTTERFIELD et al., 1990); open circle = Juan de Fuca Ridge, ASHES, Inferno (BUTTERFIELD et al., 1990); open squares = East Pacific Rise, 21°N, OBS (VON DAMM et al., 1985) and Mid-Atlantic Ridge, MARK, MARK-1 (CAMPBELL et al., 1988b).](image-url)
vapor-like fluid. In either case, the phase separation process causes a drastic chlorinity change of the hydrothermal fluid.

The first unequivocal identification of phase-separated effluent from the seafloor venting system was reported by MASSOTH et al. (1989). A variety of fluid chlorinity which ranges from 35% to 115% of seawater, was observed within a 60 m diameter of the ASHES vent field at the Juan de Fuca Ridge. BUTTERFIELD et al. (1990) studied fluid chemistry in more detail and demonstrated that the entire range of their compositions are best explained by subcritical phase separation and vapor-liquid-seawater mixing during fluid rising through the oceanic crust (see Fig. 4). Hydrothermal fluid has generated vapor and liquid phases, which have become physically segregated and followed different pathways to the seafloor, cooling and mixing to varying degrees along the way with cold seawater percolating into the interstitial matrix (BUTTERFIELD et al., 1990).

For the mechanism of phase segregation, FOX (1990) and BUTTERFIELD et al. (1990) presented their own models. FOX (1990) pointed out that the co-presence of liquid and vapor phases induce reduction in the relative permeabilities of both phases due to reciprocal interference. Brine phase fluids are confined within flow conduits being surrounded by permeability barrier, while vapor phase fluids flow diffusely. As a result, phase separated fluid leads to phase segregation. BUTTERFIELD et al. (1990) assumed a highly permeable zone associated with a fault as the fluid conduit. Based on the latter model, phase segregation is attributed by virtue of the differing buoyancy between vapor phase and brine phase along a non-vertical fluid conduit, especially at a branching point.

![Diagram](image)

Fig. 4. Diagrammatic representation of fluid circulation history in the phase-separated hydrothermal system.
CHEMICAL CHARACTERISTICS OF THE NORTH FIJI BASIN HYDROTHERMAL FLUIDS

Table 1 presents data of end-member fluid compositions of the North Fiji Basin hydrothermal system. Data of the ASHES vent field, EPR 21°N and MARK sites are

<table>
<thead>
<tr>
<th></th>
<th>North Fiji Basin</th>
<th>ASHES</th>
<th>EPR</th>
<th>MAR</th>
<th>Seawater</th>
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<tr>
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<td>White</td>
<td>STARMER</td>
<td>Virgin</td>
<td>Inferno</td>
<td>OBS</td>
</tr>
<tr>
<td>Lady</td>
<td>Mound</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>temp. (°C)</td>
<td>285</td>
<td>291</td>
<td>299</td>
<td>328</td>
<td>350</td>
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<td>Li (µM)</td>
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<td>Na (mM)</td>
<td>210</td>
<td>239</td>
<td>148</td>
<td>499</td>
<td>432</td>
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<td>K (mM)</td>
<td>10.5</td>
<td>14.5</td>
<td>6.98</td>
<td>26.8</td>
<td>23.2</td>
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<td>Rb (µM)</td>
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<td>17.1</td>
<td></td>
<td>28</td>
<td>10.5</td>
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<td>Mg (mM)</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>Ca (mM)</td>
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<td>46</td>
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<td>81</td>
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<td>Ba (µM)</td>
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<td>26</td>
<td>8</td>
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<tr>
<td>Mn (µM)</td>
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<td>26</td>
<td>142</td>
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<td>960</td>
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<td>Fe (µM)</td>
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<td>Si (mM)</td>
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<td>17.6</td>
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<td>267</td>
<td>176</td>
<td>624</td>
<td>496</td>
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<td>Br (µM)</td>
<td>306</td>
<td>407</td>
<td>250</td>
<td>956</td>
<td>802²</td>
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<td>SO₄²⁻ (mM)</td>
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<td>pH</td>
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<td>4.4</td>
<td>3.5</td>
<td>3.4</td>
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<td>alk (mM)</td>
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<td>+0.66</td>
<td>-0.48</td>
<td>-0.40</td>
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<td>H₂S (mM)</td>
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<td>18</td>
<td>7.1</td>
<td>7.3</td>
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<tr>
<td>CO₂ (mM)</td>
<td>14.4</td>
<td>11.1</td>
<td>285</td>
<td>50</td>
<td>8.0</td>
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<td>K/(K+Na)</td>
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<td>0.057</td>
<td>0.045</td>
<td>0.051</td>
<td>0.050</td>
</tr>
<tr>
<td>Li/K</td>
<td>0.019</td>
<td>0.019</td>
<td>0.026</td>
<td>0.023</td>
<td>0.038</td>
</tr>
<tr>
<td>Ca/Sr × 0.001</td>
<td>0.21</td>
<td>0.20</td>
<td>0.22</td>
<td>0.24</td>
<td>0.19</td>
</tr>
<tr>
<td>Br/Cl × 1000</td>
<td>1.2</td>
<td>1.5</td>
<td>1.4</td>
<td>1.5</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Data sources:
North Fiji Basin, Station 4: GRIMAUD et al. (1991); ISHIBASHI et al. (1994a).
Juan de Fuca Ridge, ASHES: BUTTERFIELD et al. (1990).
#Br data: CAMPBELL and EDMOND (1989).
also listed in the same table for comparison. The Virgin Mound and the Inferno are representative of the vapor-rich and the brine-rich fluid venting in the ASHES vent field. BUTTERFIELD et al. (1990) demonstrated characteristics of the ASHES hydrothermal fluids as; 1) wide range of chlorinity and co-variation of the concentrations of most major elements, 2) inverse correlation of gas content and chlorinity, and 3) depletions in iron and other metal elements of the vapor-rich fluid. The North Fiji Basin fluids show several similarities to the vapor-rich fluids in the ASHES field (GRIMAUD et al., 1991; ISHIBASHI et al., 1994a).

The chlorinity of the North Fiji Basin fluids is 47–49% of seawater, which indicates that the observed fluids are vapor-rich component. Sodium concentration is proportional to the chlorinity dilution, supporting that chlorinity modification is not attributed to fluid-mineral interactions. Ratios among some cations and anions are calculated and listed in Table 1. These ratios are similar to the EPR and MAR hydrothermal fluids as pointed by GRIMAUD et al. (1991). This coincidence implies that the initial North Fiji Basin hydrothermal fluid prior to the phase separation has a chemical composition in the range controlled by fluid-mineral interactions. This speculation of the initial fluid chemistry would be reinforced by geochemical and mineralogical characteristics of sulfide samples collected from this hydrothermal field, which are very similar to those of sediment-poor mid-oceanic ridge hydrothermal systems (BENDEL et al., 1993).

The CO₂ enrichment is notable but not so significant compared with the Virgin Mound fluid of the ASHES vent field which has an extremely high CO₂ concentration of 285 mM/kg. However, for the ASHES hydrothermal system, the extensive gas enrichment is attributed to magmatic exsolution of a CO₂-rich fluid and injection into the circulating hydrothermal fluids (BUTTERFIELD et al., 1990). Contrary to this, magmatic activity of the North Fiji Basin Central ridge is expected to have a mature, gas-depleted feature from the N-MORB-like petrology. Since gas species abundance in the hydrothermal fluid would reflect that of the magma beneath the hydrothermal system, it is reasonable to infer that the North Fiji Basin fluid does not show so high CO₂ concentration as the ASHES fluids.

Iron concentration of the North Fiji Basin fluid is significantly low. The depletion of metal elements accounts for the formation of anhydrite chimneys with very little amount of sulfides. This mineralogical occurrence is common between the White Lady and the Virgin Mound in the ASHES field. DRUMMOND and OHMOTO (1985) indicated that sub-seafloor precipitation of ore-forming metal elements is caused by phase separation. A sudden increase in the pH of the brine phase of hydrothermal fluids is induced by CO₂ partitioning into the vapor phase, which in turn control sulfide precipitation.

Also with respect to physical properties, the North Fiji Basin fluids show similar features to the ASHES fluids. Exit temperatures of venting fluids are 230–290°C, which are much lower than the boiling temperature at the seafloor condition (Fig. 3). This observation strongly suggests sub-seafloor cooling by admixture of cold ground seawater while the fluid ascends the upflow zone after phase separation and segregation (BUTTERFIELD et al., 1990).

In summary, the fluid chemistry of the North Fiji Basin hydrothermal system
at Station 4 show characteristics of the vapor-rich component of the phase-separated hydrothermal fluids. This result strongly supports the idea that the fluids have experienced phase separation and segregation during hydrothermal circulation, although counterpart brine-rich fluid have not been observed in this area.

Fig. 5. Plot of end-member elemental concentrations versus end-member chloride concentration for individual vents. Circles and crosses indicate data for the North Fiji Basin fluid and the ASHES vent field fluids (from BUTTERFIELD et al., 1990), respectively. Value of seawater is plotted as a small circle. (a) Sodium, (b) potassium, and (c) bromide.
TEMPORAL AND SPATIAL FLUCTUATION OF CHEMICAL COMPOSITIONS
OF THE HYDROTHERMAL FLUIDS

The White Lady fluid shows no significant changes in chemical composition during the two dive programs from 1989 to 1991 (ISHIBASHI et al., 1994a). This is similar to the case of the ASHES vent field. BUTTERFIELD et al. (1990) reported no composition change in the chemistry of the vapor-rich fluids during two years. In such time scale, hydrothermal fluid which undergoes phase separation would retain its chemical composition. For a single-phase hydrothermal system, CAMPBELL et al. (1988a) reported stable chemical composition during a 6-year time series sampling. It is understandable since equilibria between fluid and mineral assemblage of a green schist facies control the composition of the major elements (e.g., BOWERS et al., 1988). However, the phase-separated hydrothermal system seems to have more chances of changing the fluid composition drastically. The mixing ratio among the vapor phase, brine phase, and original single phase depend on both the phase segregation process during fluid transportation and the condensation process near the seafloor. The observations of the ASHES and the North Fiji Basin hydrothermal field suggest that these parameters are rather stable and implies that physical structure of hydrothermal circulation, for instance represented by porosity, would be maintained steadily in such time scale.

With respect to spatial variation of chemical composition, BUTTERFIELD et al. (1990) reported a diverse range of chlorinity among the fluid venting within a small area of 60 m in diameter. The fluid end-member compositions show good correlation between cation concentration and chloride concentration for individual vents (Fig. 5). This relationship indicates strong evidence that the simple mixing of a brine with a vapor of near-zero salinity causes the entire range of variation of fluid compositions. For the North Fiji Basin fluids, phase separation and segregation processes control the fluid chemistry in a 200 m wide hydrothermal field in Station 4. However, fluctuation of chemical composition between two sites, the White Lady and the southwestern venting (Kaiyo-LHOS), seems not to be so simple. Relationship between two North Fiji Basin end-members does not agree with the mixing line which contains zero salinity end-member (Fig. 5). This discrepancy is attributed to fluid interaction with conduit rocks probably after condensation just beneath the seafloor (ISHIBASHI et al., 1994a).

GAS GEOCHEMISTRY OF THE NORTH FIJI BASIN HYDROTHERMAL FLUIDS

Gas chemistry of the hydrothermal fluids collected from Station 4 on the North Fiji Basin Central ridge have similar characteristics to that of the hydrothermal systems in the mid-oceanic ridge (ISHIBASHI et al., 1994b). Data of chemical and isotopic compositions of gas species are compiled in Table 2. The MORB-like carbon isotopic compositions of both CO₂ and CH₄ indicate little influence by involvement of subducted components of organic materials and/or altered carbonates into the magma beneath the hydrothermal system. On the other hand, the helium isotopic composition seems higher than the average range of the MORB helium. This signature suggests incorporation of hot spot-like primitive component into the
Table 2. Comparison of gas chemistry of hydrothermal fluids

<table>
<thead>
<tr>
<th></th>
<th>North Fiji Basin</th>
<th>EPR 21°N</th>
<th>EPR 13°N</th>
<th>MAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ (mM)</td>
<td>14.5/11.0</td>
<td>8.0</td>
<td>10.8-16.7</td>
<td></td>
</tr>
<tr>
<td>CH₄ (µM)</td>
<td>30.4/43.5</td>
<td>45-65</td>
<td>27-55</td>
<td>61.6</td>
</tr>
<tr>
<td>He (µM)</td>
<td>1.0-2.0</td>
<td>0.9-2.2</td>
<td>3.0-4.5</td>
<td>2.0</td>
</tr>
<tr>
<td>δ¹³C(CO₂) (%PDB)</td>
<td>-6.2 to -5.7</td>
<td>-7.0</td>
<td>-5.5 to -4.1</td>
<td></td>
</tr>
<tr>
<td>δ¹³C(CH₄) (%PDB)</td>
<td>-20 to -18</td>
<td>-17.6 to -15.0</td>
<td>-19.5 to -16.6</td>
<td></td>
</tr>
<tr>
<td>R/Rₐ</td>
<td>9.0 to 10.0</td>
<td>7.8</td>
<td>7.4 to 7.6</td>
<td>8.4</td>
</tr>
</tbody>
</table>

Data sources:
North Fiji Basin, Station 4: Ishibashi et al. (1994b).
East Pacific Rise, 21°N: Craig et al. (1980); Welhan and Craig (1983).

mantle source of the North Fiji Basin Central ridge.

The gas geochemistry of the North Fiji Basin hydrothermal fluids was consistent with the petrological studies reported by Eissen et al. (1991, 1994) and Nohara et al. (1994). Basalt samples from the Central ridge are dominantly N-MORB feature (Eissen et al., 1991). The influence of subduction contamination appeared in only a few samples. On the other hand, trace elements abundance and Nd-Sr isotopic systematics suggested incorporation of the primitive component. The elevated helium isotopic signature related to the primitive component involvement is observed at several regions in southwest Pacific, such as Manus basin and the northeastern part of the Lau Basin (e.g., Poreda and Craig, 1987). The spreading process of the North Fiji Basin, especially the unique topographic rise up dome in the triple junction near Station 4, might be related to the upwelling of the primitive component.

TECTONIC AND MAGMATIC ACTIVITIES AROUND THE HYDROTHERMAL SYSTEM

In spite of the wide distribution of huge fossil sulfide chimneys in the graben, all of the active fluid venting form sulfate chimneys. Moreover, the active sulfate chimney White Lady grew up over a mound composed of the remnant of sulfide hydrothermal precipitates. These observations suggest that the present hydrothermal activity in phase-separation stage replaced the non-boiling, black-smoker type hydrothermal activity stage which had precipitated abundant sulfides in the past. During this stage transition, distribution of hydrothermal activities significantly decreased. While the extinct sulfide chimneys distribute over the graben area (2 km × 5 km), present active sulfate chimneys were limited within a narrow area (about 200 m wide). This retreat implies that the transition occurred not with an
increase but with a decrease of magmatic activity.

Because wane of magmatic activity means a decrease of heat supply for the hydrothermal system, it seems to be disadvantageous for the transition from the non-boiling to the boiling stage. However, the transition is considered to occur even in such situation, taking account of clogging effect caused by precipitation of sulfides and quartz. As the heat supply from the magma decreases, hydrothermal fluid circulation would retreat in a narrow region and the clogging within the fluid circulation zone would develop. This obstruction of fluid discharge would induce increase in hydraulic pressure and also increase in fluid temperature progressively to attain the two-phase boundary. Decrease in tectonic activity around the hydrothermal site might be necessary to maintain this boiling stage activity, because frequent fracturing events would destroy the clogged cap with new conduit formation.

With the replacement by the boiling stage, hydrothermal system may attain a new steady-state condition. Through capillary conduits in the clogged cap, only the vapor phase can eliminate to the seafloor. Total fluid mass flux transported by the phase-separated hydrothermal system is significantly low compared with the non-boiling system, but heat flux is comparable between them because the vapor-phase fluid has high enthalpy. The transition from the non-boiling stage to the boiling stage in the White Lady hydrothermal field would represent declining history of the magmatic activity in the North Fiji Basin Central ridge.

Several studies have pointed out that high-intensity ore-forming hydrothermal system develops with timing of magmatic and tectonic events to create sufficient magmatic heat supply and favorable permeability distribution (e.g., RONA, 1988). Recently, hydrothermal activity accompanying an in-progress eruption of the mid-ocean ridge was witnessed on the EPR 9°50’ N (HAYMON et al., 1993). In this site, intrusion of dikes beneath the seafloor is considered to occur. This induced phase separation of fluids near the tops of the intruded dikes and a large flux of vapor-rich hydrothermal fluids (which salinity ranging as low as 0.3 wt% NaCl) through the overlying rubby cavernous lavas (HAYMON et al., 1993). BUTTERFIELD et al. (1994) reported similar chlorinity change observed at the hydrothermal system in the north Cleft segment of the Juan de Fuca Ridge. Phase-separation in hydrothermal systems may occur when the relationship of magmatic activity and tectonic activity slightly deviates from the most favorable condition for intense hydrothermal circulation.

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REFERENCE


