

THE COOPERATIVE STUDY PROJECT
ON THE DEEPSEA MINERAL RESOURCES
IN SELECTED OFFSHORE AREAS OF THE SOPAC
REGION

(VOLUME 5)

SEA AREA OF
THE REPUBLIC OF FIJI

February 10, 2000

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

LOCATION MAP OF THE SURVEY AREA

PREFACE

In response to a request by the South Pacific Applied Geoscience Commission (SOPAC), the Government of Japan has undertaken marine geological and other studies relating to mineral prospecting to assess the mineral resources potential of the deep sea bottom in the offshore regions of SOPAC member countries. Implementation of the survey has been consigned to the Japan International Cooperation Agency (JICA). Considering the technical nature of geological and mineral prospecting studies, JICA commissioned the Metal Mining Agency of Japan (MMAJ) to execute the survey.

The survey is planned to be undertaken over a period of five years starting from Fiscal 1995. This is the last year of the project, and the target area is the Exclusive Economic Zones of the Republic of Fiji Islands. MMAJ dispatched the Hakurei Maru No.2, a research vessel fitted for investigating deep sea mineral resources, to the survey area for 29 days from May 20, 1999 to July 2, 1999, successfully completing the survey as planned with the cooperation of the Fiji Government.

The present report sums up the results of this fifth year survey in the Exclusive Economic Zones of the Republic of Fiji Islands.

It is a pleasure to record our deep gratitude to all persons concerned, particularly to the staff of the SOPAC Secretariat, Government of the Republic of Fiji Islands, as well as the Japanese Ministry of Foreign Affairs, the Ministry of International Trade and Industry and the Japanese Embassy in Fiji.

February 2000

Japan International Cooperation Agency

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Abstract

The third phase of the cooperative survey for the development of resources of the SOPAC member countries is being scheduled for implementation during a period of five years starting from 1995, and this is the fifth year. This year, the survey was carried out from May 20 to July 2, 1999 in an area of 14,500km² in the exclusive economic zones of the Republic of the Fiji. The duration of the survey was 44 days and the target mineral resources were hydrothermal mineralized zones.

In the EEZ of the Republic of Fiji Islands, the occurrence of hydrothermal deposits in the Central Spreading Ridge of the North Fiji Basin has been known from previous scientific studies. This year, the confirmation of the scale of the deposits, studies of the known mineralized zones through core sampling by sea floor Boring Machine System (BMS), and survey of seafloor topography and mineralization of the unexplored areas were carried out. But BMS core sampling could not be carried out on the known mineralized zones due to the deterioration of the weather, thus the sites of drilling were changed to an oceanic ridge in the Extensional Relay Zone and a knoll to the north.

Regarding the study of known mineralized zones, the topographic high near the Triple Junction of the Central Spreading Ridge was designated as "Area 1". Topographic survey was made for the whole area, and Side Scan Sonar (SSS), Finder Installed Deep Sea Camera (FDC) surveys and Large Corer (LC) sampling were carried out in the rift valley.

Detailed topographic map had not been prepared previously in the North Fiji Fracture Zone which extends eastward from the vicinity of the Triple Junction. Thus the area from near the Triple Junction to near the Fiji Islands was designated as "Area 2" and seafloor topographic, Sub Bottom Profiler (SBP), and geomagnetic surveys were carried out over 24nm around the Fiji Transform Fault. Studies of mineralized zones including SSS, FDC surveys and sampling were carried out on the Extensional Relay Zone near 177°20'E and a knoll to its north. These locations were selected from the results of seafloor topographic survey of "Area 2" and from previously acquired data.

At "Area 1" existence of a topographic high and a rift valley in its central part was confirmed near the Triple Junction. Possibility of chimneys and mounds existing along the fractures and small cliffs within the rift valley was recognized by SSS survey. These possible chimneys and mounds were found to be particularly densely distributed at SO99 site to the north of the known mineralization at 16°58'S. Thus FDC seafloor observation was made around this zone. The results confirmed mounds with possible chimneys at 9 localities, and discolored parts of apparent mounds at 6 localities. These were found at a topographic high on the western side of the floor of the Central Graben near 173°55.1'E, and around a depression in the central part of the graben at 173°55.3 - 55.4'E. The size of the individual mounds is about 100m in diameter. The center of hydrothermal activity at the SO99 site is at the depression in central part of the Central Graben. The results of the present survey indicate the possibility of the mineralized zone expanding further than 1km x 1km area.

In “Area 2”, E-W trending structure along the Fiji Transform Fault (FTF) such as Yasawa and Yadua Troughs, and oceanic ridge-type topographic highs are notable., associated by N-S rift structure such as Viwa Rift and ERZ A. The topographic elements are generally small, and acoustic images indicate the possibility of exposed rocks over wide range of ridges and trough slopes. Magnetic survey showed that the following three areas of notable magnetic anomalies of normal magnetization .

(1) A ridge with SW-NE trending axis at the western end of the area

(2) Northern end of the Viwa Rift

(3) Flat area between Central Hill and N-S Ridge

Of these three, (2) and (3) areas are not topographic highs, and ferromagnetic bodies are inferred to occur beneath the seafloor.

From the results of the “Area 2” survey, the following localities are considered to have the possibility of hydrothermal activities.

A. “ERZ A” between the Yasawa and Yadua Troughs,

B. “Central Hill”, a knoll to the north of ERZ A,

C. Bottom of Viwa Rift.

SSS survey, FDC survey, and CB, LC sampling and core sampling by BMS was carried out at A and B areas.

In ERZ A several spreading activities occurred between the N-S Ridge and the ridge to the west forming terrace structure and N-S Valley was the center of the youngest spreading. FDC seafloor observation showed lava flow at the deepest depression of the N-S Valley, and confirmed discoloration of rocks and sediments together with water temperature anomalies on middle slope of the eastern ridge, indicating the presence of hydrothermal activity. Basalt samples, including one with pyrite on the northern side of the deepest depression, were collected by CB and BMS core sampling. Chemical analysis of the collected rocks showed their origin to be a magma similar to mid oceanic ridge basalt

(MORB). This supports the theory that ERZ A is a spreading axis, and indicates the possibility of volcanism and associated hydrothermal activity.

Central Hill is a knoll located to the north of ERZ A and there is a valley on the summit trending in the direction of ERZ A extension. Youngest lava flow occurrence is inferred from acoustic images and magnetic anomaly distribution at a depression between N-S Valley and Yadau Trough. Mound-type topographic high was, also, observed in a valley on the summit and it extends in the ERZ A direction. Thus the possibility of hydrothermal activity in this summit valley was considered. Here, shell fragment accumulation was found over an area of 300m × 300m by FDC seafloor observation. Identification of the shell fragments collected by CB indicated the high possibility of being hydrothermal organisms. Pyrite was confirmed in the unconsolidated sediments recovered by BMS indicating intense hydrothermal activity. Gabbro, serpentine, dolerite and other rocks were collected by CB and BMS sampling, and the gabbro showed chemical composition similar to that of island arc tholeiite. Thus Central Hill is considered to have had been a part of an Island arc which subsequently was intruded by dolerite with composition similar to that of MORB. These facts indicate that sulfide mounds occur beneath the unconsolidated sediments although it was not possible to confirm during the present cruise.

The scale of the known ore deposit in SO99 site of Area 1 and the possibility of the occurrence of hydrothermal mineralization in Area 2 were surveyed this year.

The areal extent of SO99 site of Area 1 is about 1km x 1km, and this range of hydrothermal activity is inferred to be not smaller than that of the Manus Basin, if not larger. The amount of collected samples, however, is small and accurate chemical data are not available and the scale of the activity could not be clarified.

In ERZ A of Area 2, a basalt sample containing pyrite was collected, and discoloration possibly due to hydrothermal alteration was found in parts of the slope at N-S Valley - N-S Ridge. In Central Hill, colony of dead bivalves was found over an area of 300m × 300m, and pyrite occurs in unconsolidated sediments at the same locality. These facts indicate that sulfide mound formed by hydrothermal activity could possibly occur under the unconsolidated sediments.

In the future, it would be desirable to confirm detailed nature of the mineralization including the grade and extent by sampling the chimneys and mounds of SO99 site in Area 1. BMS survey to locate mounds under unconsolidated sediments at Central Hill is, also, desired.

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Chapter 1 Outline of the Survey

1-1 Survey Title

The Fiscal 1999 Joint Basic Study for the Development of Mineral Resources (Study for Marine Resources) in the Exclusive Economic Zones of the Republic of Fiji Islands.

1-2 The Purpose of the Survey

The purpose of the survey is to assess the potential of submarine mineral resources within the Exclusive Economic Zones of the Republic of Fiji Islands, a member of SOPAC, through submarine topographical survey, sampling and other surveys.

1-3 Survey Area

The survey areas for this study are the areas (Area 1 and Area 2) within the polygons connecting the points shown below.

Area 1			Area 2		
	Latitude	Longitude		Latitude	Longitude
A	16°50'S	173°50'E	A	16°18'S	175°00'E
B	16°50'S	174°00'E	B	16°30'S	178°00'E
C	17°05'S	174°00'E	C	16°30'S	178°00'E
D	17°05'S	173°50'E	D	17°18'S	175°00'E
A	16°50'S	173°50'E	A	16°18'S	175°00'E

These areas were selected in accordance with the joint study program for marine mineral resources in the exclusive economic waters of the SOPAC member countries agreed upon by the Japanese executing agency and the South Pacific Applied Geoscience Commission (SOPAC) on 13 March 1995.

1-4 Duration of the Survey

Survey cruise: May 20 to July 2, 1999

Analysis and other work: April 1, 1999 to March 31, 2000

1-5 Survey Participants

Coordinator

Japanese participants

Katsutoki Matsumoto (Metal Mining Agency of Japan)

Yoshiyuki Kita (Metal Mining Agency of Japan)

Maki Sekimoto (Metal Mining Agency of Japan)

Fijian participant

Bhaskar Rao (Mineral Resources Department)

SOPAC participants

Alfred Simpson

Russell Howorth

Jackson Lum

Kazuhiro Kopjima

Participants of Field Survey

Japanese participants

Field supervisor

Kokichi IIZASA (Geological Survey of Japan) (14 Jun ~ 2 Jul)

Observer:

Kazuhiro KOJIMA (SOPAC) (17 Jun ~ 2 Jul)

Members:

	Toshio KOIZUMI	(DORD)	(14 Jun ~ 2 Jul)
Leader	Kohei MAEDA	(DORD)	(20 May ~ 2 Jul)
	Nadao SAITO	(DORD)	(20 May ~ 2 Jul)
	Nobuyuki MURAYAMA	(DORD)	(20 May ~ 2 Jul)
	Masatsugu OKAZAKI	(DORD)	(20 May ~ 13 Jun)
	Kazunori MATSUI	(DORD)	(20 May ~ 13 Jun)
	Junzo YOSHIWAKA	(DORD)	(20 May ~ 2 Jul)
	Hiroyuki II	(DORD)	(20 May ~ 13 Jun)
	Tetsuya NISHIKAWA	(DORD)	(20 May ~ 2 Jul)
	Takehiro BUTO	(DORD)	(20 May ~ 2 Jul)
	Tadashi SATO	(OED)	(20 May ~ 2 Jul)
	Yutaka HASHIMOTO	(OED)	(20 May ~ 2 Jul)
	Noboru ICHINOSE	(OED)	(20 May ~ 2 Jul)
	Susumu KANZAKI	(OED)	(20 May ~ 2 Jul)
	Toshimitsu TANAKA	(OED)	(16 Jun ~ 2 Jul)
	Kazuhiko TANAKA	(OED)	(20 May ~ 16 Jun)
	Yoshinori MATSUKAWA	(OED)	(20 May ~ 2 Jul)
	Yukari SHIMIZU	(OED)	(20 May ~ 2 Jul)

Consigned Participants

Trainee	Mr. Wong Hen Loon	(Republic of Fiji Islands)	(20 May ~ 13 Jun)
	Mr. Viliame Lutu Baleivanualala	(Republic of Fiji Islands)	(16 Jun ~ 2 Jul)

1-6 Survey Achievements

Survey operations were accomplished as shown in [Table 1- 6-1](#) and the itinerary of the survey is shown in [Table 1-6-2](#).

1-7 Survey Apparatus and Equipment

Major apparatus and equipment used during the survey are shown in [Table 1-7-1](#) and the photographs in [Figure 1-7-1](#).

Chapter 2 Survey Methods

2-1 Survey Plan

Fiscal 1999 is the last year of the Third Phase Five Year SOPAC Program, and the mode of occurrence of mineral resources in the EEZ of the Republic of Fiji Islands was surveyed. The target of the survey for this year is hydrothermal mineralization.

In the EEZ of the Republic of Fiji Islands, the past studies have shown that hydrothermal deposits occur around the Central Spreading Ridge of the North Fiji Basin. Thus regarding the known deposits and mineralized zones, confirmation of the size of the deposits and Boring Machine System (BMS) core sampling of the mineralized zones were carried out; and seafloor topographic survey and mineral exploration were carried out in areas where mineralization is yet unknown.

In the known mineralized areas, topographic survey was carried out at the topographic high near the Triple Junction of the Central Spreading Ridge. Side Scan Sonar (SSS) survey was done in an area including White Lady site, Pere Lachaise field, and SO99 site within the rift-valley. Finder Installed Deep Sea Camera (FDC) survey and Large Corer (LC) sampling were made around the SO99 field where the seafloor is believed to be relatively flat in spite of the concentration of the mounds. The above area where topographic survey was carried out is named "Area 1".

Accurate topography is not known in the North Fiji Fracture Zone, which extends eastward from the Triple Junction of the Central Spreading Ridge. Therefore, seafloor topographic map, acoustic image map, magnetic total intensity map and others were prepared for a length of 24nm in the N-S direction around the Fiji Transform Fault. This area extends from near the above Triple Junction to near the Fiji islands. This area is named "Area 2".

From the results of the study of the "Area 2" and existing documents, Extensional Relay Zone near 177°20' E and a small knoll to the north were selected for mineral exploration, and SSS, FDC, sampling, and other work were carried out.

BMS core sampling was originally planned for the known mineral deposits at the Triple Junction, but the plan had to be changed due to the deterioration of the weather conditions and sampling was carried out at the oceanic ridge of the Extensional Relay Zone and the small hill to the north.

After the completion of the survey cruise; identification and analyses of the samples, analysis and integrated study of the data were carried out on land, and the results are incorporated in this report.

2-2 Numbering

The numbering system for sampling sites is as follows.

[For CB and LC sampling points]: Year - SF - Equipment used - Sampling No.

S denotes SOPAC, F denotes Fiji. Sampling sites were numbered sequentially regardless of Areas 1 or 2.

Examples: 99 SFCB01 (CB used)

99SFLC02 (LC used)

[BMS sampling sites]:

Year - SF - BMS - Sampling No.

Drilling sites were numbered sequentially from 01 regardless of survey area.

Example: 99SFBMS01

[SSS track lines]:

Year-SF-SSS-No.

Track lines were numbered sequentially from 01 regardless of Areas 1 or 2.

Example: 99SFSSS01

[FDC track lines]:

Year - SF - FDC - No.

Track lines were numbered sequentially from 01 regardless of Areas 1 or 2.

Example: 99SFSSS01

[Acoustic survey track lines]:

Year-Month-Day-Track line number.

Example: 990615

2-3 Position Locating

The position of the survey ship was determined by GPS.

The position of the towed vehicles (FDC, SSS, etc.) was calculated by Pythagorean theorem from the water depth measured by the depth sensor on the vehicle and the cable length, under the assumption that the vehicles were located directly behind the ship. The geodetic coordinates used for the measurement were WGS84.

The position of the sampling sites of dredges (Armed Dredge: AD, Chain Bucket :CB) and large corer (LC) was shown by the ship's position at the time of the sampler reaching the bottom. The water depths were calculated from the depths of the TD sensor data attached to the tow line.

The position of the sampling sites of the sea bottom drilling machine (BMS) was shown by the GPS position of the survey ship at the time of the drill reaching the seafloor, and the water depth was determined by acoustic sounding.

2-4 Topographic and Acoustic Surveys

Seafloor topographic survey was carried out over parallel track lines with 1nm intervals with ship speed of 10~12 knots. Sounding by MBES was made every 8~12 seconds and every 8 seconds by NBS. During MBES topographic survey, acoustic reflection intensity from the seafloor can be obtained. Surface section of the seafloor was surveyed parallel with the topographic survey.

SSS survey was carried out at the rift valley of Area 1 and at Extensional Relay Zone of Area 2. The SSS track lines were over the direction of the extension of the known mineralized zones and the extension of the structure.

2-5 Magnetic Survey

Magnetic survey was carried out with the purpose of clarifying the magnetic structure of the survey area in order to obtain information useful for mineral prospecting. PGM sensor was towed from the stern in order to avoid the magnetic effect of the ship. The distance between the ship and the sensor was 770m. Total magnetic intensity was measured every 6 seconds with 0.1nT resolution. The measured data were recorded in on-line computer every 10 seconds and processed.

Tri-axial magnetometer measurement was carried out together with the above magnetic survey.

2-6 Seafloor Observation and Photography

Seafloor was observed by towing, at about 1- knot speed, FDC equipped with still and TV cameras, and CTD. The seafloor was photographed by color TV and still cameras. The obtained seafloor images were recorded in VTR.

The track lines were set over localities with mineral potential interpreted from the results of previous studies, topographic surveys, and the extension of known mineralized zones

2-7 Sampling

Sampling was carried out in order to confirm the mineralization and to clarify the geology of the survey area. LC, CB, and BMS were used for sampling rocks and sediments. The sampling sites were selected on the basis of the results of FDC observation.

The collected samples were described and photographed on board, sealed and were sent for various examinations.

The following analysis and tests were carried out.

For fresh volcanic rocks, thin section microscopy, chemical analysis, and Ar-Ar dating were carried out. For rock samples on which mineralization or alteration were observed, thin section microscopy, chemical analysis, and X-ray diffraction was carried out. Chemical analysis was, also, done on sulfides and manganese oxides attached to the recovered rocks. Identification of microfossils, identification and classification of biological remains were made as necessary.

2-8 Seawater Survey (CTD Measurements)

In order to determine the sonic velocity profile and the water depth of the sampling sites, water temperature and water depth data were obtained by attaching memory-type TD to LC and CB during sampling.

In order to detect the indications of hydrothermal activity, water temperature data were obtained by installing a thermometer on SSS. An on-line CTD was, also, installed on FDC and data regarding water temperature, salinity, and water depth were obtained and were used as basic data for interpreting the survey results.

2-9 Processing and Analysis of Survey Data

The processing and analysis of obtained data were carried out as shown in the flow sheet of [Figure 2-9-1](#). Basic data were processed and analyzed onboard and various laboratory tests and research work were carried out on land, and the present report was prepared incorporating the results of all the above work.

Chapter 3 Survey of the Mineralized Zones of Area 1

In Area 1, seafloor topographic mapping, SSS survey, clarification of distribution of the chimneys and mounds by FDC seafloor observation, and collection of ore samples (sulfides) by BMS were planned for the mineralized zones at the Triple Junction which connects SO99 site to Pere Lachaise, STARMER II-White Lady. But core sampling by BMS was prohibited by deterioration of the weather conditions.

The topography and structure of the triple junction and the results of the survey of Area 1 are outlined below.

3-1 Outline of the Surveyed Marine Area

3-1-1 Topography and Structure of the North Fiji Basin

The seafloor topography of the southwestern Pacific including the North Fiji Basin is largely believed to be as shown in [Figure 3-1-1](#).

This area is at the boundary of the India-Australia Plate and the Pacific Plate and is called the Melanesian Borderland. Island arcs and marginal seas are developed in this area. The basins along this plate boundary, namely Manus Basin, Woodlark Basin, North Fiji Basin, and Lau-Havre Basin are typical marginal sea basins where seafloor spreading was confirmed.

The North Fiji Basin is the largest of these basins, it is 2,500m ~ 3,000m deep and is bordered by Vityaz Trench to the north, Vanuatu Arc to the west, New Hebrides Trench-Hunter Fractured Zone to the south, and the Fiji Islands to the east.

The major structure of the North Fiji Basin is shown in [Figure 3-1-2](#). The seafloor topography is complex with occurrence of oceanic ridges, seamounts, knolls and depressions among them. These structures occur in parallel or in an echelon manner. The following large linear structures are observed:

- 1) Many linear structures in the N-S direction near the center of the basin and a line of small rises in the central part (Central Spreading Ridge).

- 2) A line of small rises and trough structure from the northwestern part of the basin toward the center (Central Spreading Ridge).
- 3) Lines of intermittent topographic highs and depressions extending from the central part of the basin via north of Fiji Islands to the Tonga Trench (North Fiji Fracture Zone).
- 4) N-S trending depression and topographical highs west of the Fiji Islands
- 5) NE-SW trending topography developed in the northeastern to the western part of the basin overlapping the morphology mentioned in 2.

From the past studies, it is understood that; 1), 2) form rift system, and 3), 4) are fracture zones associated with the rotation of the Fiji Islands, and the intersection of 1), 2), and 3) form the Triple Junction of the spreading axes (Malahoff et al., 1982, Auzende et al., 1988a and other literatures). A theory that 5) is a fracture zone traversing the basin has been forwarded (Chase, 1971).

The clear spreading axis at present is the structure in the N-S direction, but in the early stages of the basin formation at 8 ~ 10 Ma, E-W trending spreading axes 2) and 3) were formed (Malahoff et al., 1982), and around 3 Ma the N-S axis was formed (Auzende, et al., 1988). Rock magnetism measurements show that Fiji Platform rotated 90° anticlockwise after 7 Ma, while Vanuatu Arc rotated 30° clockwise after 6 Ma. These movements were caused by changes of plate movements described below (Falvey, 1978, others).

Before the formation of the North Fiji Basin, the Pacific Plate was being subducted southwestward from the Vityaz Trench on the northern side of the basin. Subsequently the India-Australia Plate began to subduct from the west by the collision of the Ontong-Java Plateau, and the present New Hebrides Trench and its backarc basin namely the North Fiji Basin were formed. The old Vityaz Arc was cut apart by the formation of the basin into the present Vityaz Arc and the Vanuatu Arc (Carney et al., 1985).

3-1-2 Topography and Structure of Triple Junction

Topography of the area near the Central Spreading Ridge (CSR) is shown in [Figure 3-1-3](#).

An annular depression is observed at 16°57'S, 173°55.5'E near the CSR. This is the Triple Junction from which central grabens extend in three directions of SSW, NNW, and NE. These grabens form the spreading centers. The linear trough topography extending south-southwestward from this junction is the Central Graben, and the rise of this part forms a topographic high extending for about 10 km.

In this area, STARMER PROJECT (1987 ~ 1992, Japan-France cooperative project) and the German Hyfiflux Project (1995) and others were carried out, and chimney-mount groups such as STARMER II - White Lady site, Pere Lachaise site, SO99 site were discovered. Thus the area is considered to be an active spreading zone (Auzende et al., 1995, others).

Topographic features extending north-northwestward and northeastward from the junction are also composed of deep troughs of the central graben which cuts through the oceanic ridge type plateau. The structure extending northeastward continues to around 16°30'S, 174°30' E, and is connected to the North Fiji Fracture Zone (FFZ) in the east through transform faults.

The Triple Junction is inferred to have formed by the following process.

- 1) There were spreading activities which formed the plateau-type high on the northwestern side on the seafloor about 3,000 m deep.
- 2) A depression with NE trending axis which cuts through the above was formed.
- 3) Activities around the SSW trending spreading system began on the southern side of the Triple Junction, and the present topography was formed.

The age of the spreading system activity is estimated to be 3 Ma for 1) and 0.7 ~ 0.4 Ma for 2), 3) mostly from magnetic studies.

3-2 Seafloor Topography and SBP of Area 1

- (1) Seafloor topography

Seafloor topographic map, hillshade map, and three-dimensional map are shown in [Figures 3-2-1, 3-2-2](#) and [3-2-3](#).

The CSR near the Triple Junction extends from 3,000m water depth of the basin depression and from near 2,700m depth, through several ridges of 2,500m, to the topographic high with water depth of less than 2,000m in the central part. In order to clarify the mineralization area of the spreading axis, MBES seafloor topographic survey was carried out for understanding the general configuration of the topographic high, and a topographic map focused on zones shallower than 2,100m was prepared.

The topographic high has an area of about 20km x 12km, and is egg-shaped. The shallowest part is 1,860m deep, and the northern slope is relatively steep while the southern slope is gentle. A 2km-wide valley extends in the NNE-SSW direction cutting through the central part of the topographic high. Thus the knoll is divided into two parallel ridges by the central valley. Both sides of the valley are steep with relative heights of 40 ~ 60m.

Within the mapped area (Area 1), the water depth of the Central Valley floor extending south-southwestward from the Triple Junction, is shallower on the junction side and deeper at 2,230m on the southern side. The valley floor forms a step-wise terrace of two to three steps, and the central part is deep.

Depressions exceeding 2,400m depth occur to the northeast, northwest, southeast, west-southwest of the topographic high. Depths of the areas outside of the prepared map exceed 3,000m and reach 3,500m in some parts. These relatively large-scale depressions and the ridges extending in the same direction on both sides of these depressions suggest that they are older than the trough in the topographic high (Tanahashi, 1990).

(2) SBP survey

SBP survey was carried out with the objective of clarifying the distribution of the seafloor sediments. SBP records are shown in [Figure 3-2-4](#).

The nSBP equipment used has high resolution, but acoustic reflection cannot be obtained where the slope of the seafloor exceeds 5°. The seafloor of the survey area is full of relief and there are many parts with slopes steeper than 5°, and thus clear continuous records could not be obtained in many places.

The obtained SBP records can be classified into two types. Examples of schematic records are shown in [Figure 3-2-4](#). Type 1 shows a homogeneous acoustic opaque layer immediately below the

seafloor while granular acoustic opaque layer is seen in Type 2. Both of these indicate exposed bedrock or thin layer of sediments.

In this area, SBP survey did not encounter localities covered by sediments exceeding several meters in thickness.

(3) MBES acoustic reflection intensity images

By MBES survey, the acoustic reflection intensity (acoustic pressure) data from the seafloor is obtained together with the seafloor topography. These reflection intensities were processed, and shown as images. Observed acoustic intensity is strongly affected by the incident angle of the acoustic wave to the seafloor. The effect of back scattering of the acoustic waves was corrected by obtaining the residual value between the observed and mean acoustic reflection intensity for each incident angle as follows. Correction for output level, TVG, and distance attenuation were made and the mean acoustic reflection intensities of the resultant data for incident angles for 0 ~ 90° were obtained, and the residue was used as the corrected intensity.

The acoustic intensity levels acquired by the above were prepared as light and shade of the images. These are shown in [Figure 3-2-5](#).

Generally, the level of MBES acoustic reflection intensity reflects the nature of bottom sediments and the seafloor topography. Namely the acoustic intensity is high where the bedrock is exposed such as oceanic ridges and knolls, while it is weak where the seafloor is covered by sediments and the acoustic reflection intensity varies by the density of the sediments. In exposed areas, however, the reflection intensity is lowest in the shadows of the topographic highs. The acoustic images of the present survey area generally show the above pattern.

In the vicinity of the Triple Junction, topographic structures extend in three directions, namely the SSW, NNW, and NE from the topographic high around 16°58'S, 173°55'E. But in the acoustic reflection intensity images, two linear structures in the SSW and NNE directions were notable. The structure in the NE direction was also seen, but it is weak compared to the other two. The acoustic level is high around NNE-SSW. This indicates thin cover of unconsolidated sediments and exposure of relative fresh rocks. On the other hand in Area 1, acoustic reflection intensity is low at; topographic high at the eastern margin, depression at the western margin, topographic high-depression-topographic high in the northeast to north. This fact indicates the existence of relatively thick sediments in the above areas compared to the NNE-SSW trending high acoustic intensity zone through the central part.

- Locally, the following characteristics regarding the acoustic intensity distribution are noted.

- The acoustic reflection intensity is high at the two SSW-trending ridges extending from the central high.
- The shallowest part has the highest intensity indicating that the unconsolidated sediments are thin.
- There are linear structures along the axis of the low zone between the two ridges and sediments occur on the trough.
- The acoustic intensity is the highest at the deepest part (16°56.2' ~ 58.7' S) between the two ridges indicating thin sedimentary cover.
- At the southwestern end of the depression which extends in the NW direction from the Triple Junction, a linear zone with relatively high acoustic reflection intensity indicating thin unconsolidated sediment cover is observed.
- The acoustic reflection intensity is low on the N-S trending ridge at the eastern margin of the area, and unconsolidated sediments occur.
- N-S trending high acoustic reflection intensity zone occurs along the shallowest part of the 2,460m deep basin in the southern part of the depression between the above two ridges and the ridge at the eastern margin of the area.
- The topographic structure of the low zone below 2,500m water depth in the northeastern part largely trends NW-SE, but locally SSW-NNE structures are observed and the acoustic reflection intensity is high along this local structure indicating low development of sediments.

3-3 SSS Survey

SSS survey was carried out with the objective of clarifying the seafloor conditions of the Central Graben near the Triple Junction where known mineralized zones such as STARMER II-White Lady, Pere Lachaise, SO99 occur. In addition to this, understanding the distribution of hydrothermal mounds, if possible, was another objective.

The survey lines and mosaic image of SSS are shown in [Figures 3-3-1](#) and [3-3-2](#), respectively. . The track lines were arranged over a distance of 8km in the N-S direction, and the center of the track lines was placed at the western side of the trough so that the main parts of the center of the mineralized zones could be observed. The valley at this part is 2km wide, and the water depth is shallow at the center of the Triple Junction and becomes deeper on the southern side. There is a slope with 30 ~ 40m relative height near the center of the E-W cross section, and it becomes deeper to the west. Thus this part was the focus of observation.

Linear structures reflecting fractures or stairstep structures parallel to the trough extending in the N15°E direction are clearly seen in the SSS images. In general, the western deeper part shows deeper tone of the image indicating higher reflection intensity than the terrace on the eastern side. This fact indicates less sediment distribution to the west. Within the same western side of the trough floor, south of latitude 16°59.0' ~ 59.5'S tone of the SSS image becomes darker, indicating higher reflection intensity. The N-S linear structure shows a small gap near the above 16°59.0' ~ 59.5'S. The high reflection intensity similar to the southern side occurs only toward the central part of the valley in the northern side. These zones with high reflection intensity are considered to be areas with relatively new outcrops.

Parts with particularly low reflection intensity or no reflection at all are observed along the western side of the valley floor in the northern side. Local depressions occur sporadically in these parts.

Protruding topography which possibly are chimneys and mounds are observed in some stairstep topography and fractures which are shown as linear structures. These possible chimneys and mounds occur notably to the north of 16°60' S and they occur densely in sporadic sites to the north of 16°58' S.

3-4 FDC Survey

FDC observation was carried out in the area around SO99 site where the known mineralized zones are said to occur most densely. The survey area was at the northern edge of the trough on the knoll summit near the Triple Junction where many protrusions were discovered by the SSS survey.

The distribution of the mineralized zones observed by FDC and bathymetry are shown in [Figure 3-4-1](#). FDC data are laid out in Attached Table 1.

3-4-1 Topography and geology

The bathymetric map showing the distribution of mineralized zones in [Figure 3-4-1](#) was prepared

by using CTD attached to the FDC frame during observation. Data were not obtained in the northeast, southeast, southwest, and northwestern parts, and thus the chart is not accurate in these parts. FDC water depth profile prepared by projecting FDC track lines on E-W section is shown in [Figure 3-4-2](#).

The relative depth between the summits of this area and the bottom of the troughs is 80 ~ 90m, and the bottom of the troughs is generally flat. It is seen on the profile that there are terraces near 60 ~ 70m of relative depth on the western wall of the troughs, and wide terraces on the eastern side correspond to the above. The most active seafloor is at deeper zones. Several N-S trending undulations are observed on the trough floor, and their relative height ranges from 30 ~ 40m at the western end to several meters in the central part.

A still photograph of representative rocks observed by FDC are shown in [Figures 3-4-3](#) and [3-4-4](#), and the distribution of cliffs and fractures in [Figure 3-4-5](#).

In the FDC images, occurrence of sheet lava was observed on the western slope and the bottom of the troughs. Caved-in structures and remnants of columns indicating the existence of lobate lava and lava pond were observed in the depressions in the southern and central parts of the trough floor. Pillow lava occur locally along fissures and forms a rise of several meters on the flat seafloor formed by sheet lava.

The seafloor is generally thinly covered by pelitic unconsolidated sediments. Talus is observed in the lower parts of the trough slope and steps. The talus consists mostly of lava pebbles of several tens of centimeters and some show columnar shape.

3-4-2 Water temperature anomalies

Water temperature was measured simultaneously with seafloor observation by attaching CTD to the FDC frame. The water temperature was monitored on real-time and recorded in the memory system.

The changes in water temperature exceeding $1/500^{\circ}\text{C}$ were extracted as temperature anomalies. Temperature variation due to water depth was considered during this anomalous temperature extraction. The distribution of water temperature anomalies is shown in [Figure 3-4-6](#). The time-water temperature profiles are combined with the SSS measurements and are shown in [Attached Figure 2](#).

Temperature anomalies were observed at 22 points. The largest anomaly was 0.077°C . Chimneys, mounds, sulfur patches, and strong discoloration of rocks and sediments was observed by FDC at 13 of the above temperature anomalous zones. Of the remaining nine points, six were covered by sediments, and pillow lava occurs at one locality.

Three anomalies exceeding 0.04°C are aligned in the N-S direction in the central part of the survey area. Chimneys and mounds were observed by FDC at two localities on the southern side. At the remaining locality in the north, the seafloor surface is covered by sediments, but pillow lava is observed in some parts, and strong discoloration is confirmed on the sediments and exposed rocks.

Relatively large temperature anomalies of 0.02 ~ 0.03°C occur sporadically to the south of 16°57.6' S. Chimneys and mounds were found at two localities on the eastern side. One anomaly at the intersection of FDC 01 and FDC 05 track lines on the western side is covered by talus, but chimneys and sulfur patches were confirmed in the vicinity. Two anomalies on the southern side are covered by sediments. Of these two, the one on the eastern side is aligned linearly with three points with anomalies higher than 0.04°C.

3-4-3 Distribution of organisms

The distribution of bio-community observed by FDC is shown in [Figure 3-4-7](#).

Colonies of hydrothermal organisms were not confirmed by the present FDC observation. Although it was not clearly confirmed by still photographs, white shrimps were observed on a chimney confirmed by FDC 03. Several centimeters-long yellow tubes were, also, observed on mounds at three localities, these could be nests of lugworms. These are possibly hydrothermal organisms. Accumulations of white shell fragments were found on mounds at three localities.

The amount of organism was generally small in the survey area, lithophytes such as sponges, and benthic organisms such as sea urchins and sea cucumbers were confirmed by FDC, but densely populated localities were not found.

3-4-4 Distribution of mineralized zones

Mineralized zones and localities where signs of hydrothermal activities were found are shown in [Figure 3-4-1](#) and [Attached Table 1](#). The mineralized zones and signs of hydrothermal activities detected by FDC images are:

- Existence of fumaroles, and pinnacles discolored to reddish brown, dark red, green, yellowish brown with high possibility of chimneys.

- Mounds discolored to reddish brown, dark brown, green, and yellowish brown.
- Yellow discoloration considered to be effusion of sulfur.
- Discoloration to iron rust color.

Chimney and mound groups were found in more than ten localities on the track lines. Mounds with chimneys extending close to 100m were found in about ten localities, and mound topography with strong discoloration of rocks and sediments without confirmed chimneys were observed in several localities. Topographic features considered to be chimneys were observed in more than 50 localities on the image.

These mineralized zones occur around the topographic high of 173°55.1'E at the bottom of the trough and also in the depression at 173°55.3 ~ 55.4'E, and they are aligned in the N-S direction. The chimneys and mounds occur along the fissures and small cliffs which are relatively numerous in the vicinity. The relief of the floor of the Central Graben is about 30 ~ 40m at the western end. Mounds were observed near the depression where the relief is the largest, and at the western ridge of the graben.

Photographs of representative chimneys and alteration zones are, respectively, shown in [Figure 3-4-8](#) and [Figure 3-4-9](#). The surface of the chimneys is generally pale brown to brown by discoloration or attachment of precipitation. But some have gray to grayish green color. The height of the chimneys is mostly 1 ~ 2m, but those exceeding 3m are observed in several localities.

3-5 Results of Sampling

Sampling was attempted at two localities LC 04 and LC 05, and it was successful at site LC 04. Sample location and description of samples are shown in [Fig. 3-4-1](#) and [Table 3-5-1](#). Columnar sections and seafloor photographs are shown in [Attached Figure 3](#).

Seafloor photograph of LC04 shows that at this locality, thin pelitic sediments cover sheet lava, and rocks and sediments are discolored unevenly to reddish brown, and parts of the sediments are yellowish brown to yellowish white.

Greenish gray altered rock samples were obtained at this locality. Minute idiomorphic crystals of pyrite and black network of pyrite are attached on the surface of this sample. The maximum diameter of the pyrite crystals was 1mm. A photograph of sections of the obtained cores are shown in Attached Figure 3.

Heat flow measurement was attempted together with sampling at site LC 05. But it seems that the LC overturned after reaching the seafloor, and the temperature within the sediments could not be measured, but sensor No. 4 attached to the upper part of the LC confirmed the rise of temperature at the surface of the sediments.

3-6 Results of Laboratory Tests

3-6-1 Thin section microscopy

Thin section observation card is shown in [Attached Table 3](#) and the results of thin section microscopy are listed in [Table 3-6-1](#).

Thin section revealed that the sample is an aggregate of irregular-shaped opaque minerals of 0.1 ~ 0.3mm in size.

This sample was inferred to be a massive sulfides ore constituting mound.

3-6-2 Chemical analysis

Chemical analysis of the rocks was carried out for 14 major components and 35 minor elements. The analyzed elements and the limits of detection are listed in [Table 3-6-2](#).

Analytical methods used for various elements are shown in [Table 3-6-3](#). In preparation for analysis, the pyrite crystals on the surface were carefully removed, desalted thoroughly, and was dried to constant weight.

Analytical results are laid out in [Table 3-6-4](#).

The results of the analysis showed the Fe content to be 39.92wt %, and the sample is inferred to be a piece of massive sulfide ore constituting mound.

3-6-3 Results of X-ray diffraction

X-ray diffraction was carried out in order to identify the constituent minerals of the sample. Sample was first dried naturally, pulverized in agate mortar, and aluminum holder was used.

X-ray diffraction charts are laid out in [Attached Figure 5](#). Electron microscopy was also carried out and the photographs are shown in [Attached Figure 8](#).

By x-ray diffraction, a large amount of pyrite, and some marcasite and calcite were identified. Peaks representing silicate, clay and other rock-forming minerals were not observed.

A large amount of small spherical (maximum 5 μ m) amorphous silica was observed attached on the surface of pyrite and marcasite by TEM. But as they are amorphous, silica mineral peaks do not appear on the x-ray charts.

3-6-4 Sulfur isotope analysis

Sulfur isotope ratio of pyrite from the sample was obtained.

The results of the analysis are shown in [Table 3-6-5](#).

The $\delta^{34}\text{S}$ diagram for massive sulfide deposits are quoted from Barnes (1979) in [Figure 3-6-1](#), and the frequency distribution of sulfur isotope ratios for recent seafloor hydrothermal activities are shown in [Figure 3-6-2](#) (Sakai and Matsuhisa, 1996).

The value of the ratio from the present sample is $\delta^{34}\text{S} = 0.5 \pm 0.2\text{‰}$. This is close to that of Kuroko ores which are believed to be of Tertiary seafloor hydrothermal origin, and is close to the value of $\delta^{34}\text{S}$ of pyrite in hydrothermal system of mid-oceanic ridge (MOR) (EPR21) in [Figure 3-6-2](#).

3-6-5 Polished section microscopy

The results of microscopic observation of the polished section and the photographs are shown in Table 3-6-6 and Attached Figure 8.

The sample (LC04A) is, mainly consists of pyrite and marcasite with minor amount of chalcopyrite and sphalerite. Pyrite, less than 0.2mm across, shows euhedral to anhedral grains, while marcasite, less than 0.2mm across, shows subhedral to anhedral grains and is associated with pyrite.

An association of subhedral to anhedral grains of chalcopyrite and anhedral grains of sphalerite is occasionally found filling cavities of pyrite grains.

In addition to those, a trace amount of barite, less than 30 μm across, and pyrrhotite, less than 10 μm across were observed by electron microscopy.

3-6-6 Summary of experimental results

The collected sample consists of small grains of pyrite and marcasite, and is considered to be a piece of ore from a hydrothermal mound. It consists largely of pyrite, but also contains medium amount of marcasite, and shows the characteristics of low temperature hydrothermal deposits. The amorphous SiO_2 on the surface is believed to have coagulated from the hydrothermal solution together with calcite simultaneously or after the precipitation of iron sulfides.

The hydrothermal sulfides in the western Pacific is characterized by the relatively low content of iron compared to those of EPR, but samples with exceptionally high iron content were collected from North Fiji Basin and Lau Basin (Ishibashi and Urabe, 1995). The present sample also has high iron content and the massive sulfide ore of CSR are considered to be one similar to MOR type. Sulfur isotope ratio was analyzed in the present survey. The results showed that the $\delta^{34}\text{S}$ value of the pyrite in the sample is close to that of the hydrothermal pyrite from mid-oceanic ridge (MOR, EPR21).

3-7 Hydrothermal Deposits in Area 1

Although observation by images only, chimney-like structure was confirmed on mounds at nine localities, and discolored localities interpreted to be mounds were observed at several localities during the present survey.

The area of hydrothermal activity ascertained by this survey is shown in [Figure 3-7-1](#). The base map for this figure is the mineralized zone map (FU Berlin and Partner, 1998) of Site SO99 by R/V Sonne, and the location of the Pere Lachaise mineralization and the results of the present cruise are laid over it. There are problems; such as the published area of mineral distribution of SO99 site by R/V Sonne is small, methods and accuracy of survey is not clearly known, and thus the overlay locations are not very accurate. The map, however, is considered to be sufficiently accurate for interpretation.

The chimney marks of R/V Sonne are concentrated at the topographic high on the western side of central axial valley of SO99 site (near 173°55'E, 16°57.5'S) and in the central depression (two localities around; 173°55.25'~55.4'E, 16°57.55'S, 16°57.7'S).

This trend was not confirmed by the present cruise because the survey density is coarse. The results show a relatively high possibility of mineralization in the central depression, but the mineralization of the western topographic high is hardly observed. This is believed to be caused by the mechanism of the FDC towing system was more suited for observation of the slope to the foot of the knolls while the chimneys of this part occur near the summits of the small hills.

The center of the present hydrothermal activity at SO99 site is at the central depression of the Central Graben, and the results indicate the possibility of wider distribution of the ore deposits.

As seen in the overlay of [Figure 3-7-1](#), the survey results show that the mineralization in the central depression of the Central Graben occurs around the slope of the step topography leading to the deepest part of the depression. The distribution of the mineralization tends to extend further to the surrounding zones.

At the topographic high to the west of the central valley floor, notable mounds occur on the high in the central part (around 173°55.06'E, 16°57.55'S) rather than on the rise with the largest relative height in the western edge. The mineralization tends to occur along the rise extending northwestward. The water temperature anomalies are also observed by CTD during the FDC survey with the center at the above two localities indicating the high possibility of presently active hydrothermal activities at these sites.

An altered zone believed to be a mound-chimney system was, also, observed at the western

shoulder near the summit of the topographic high in the Central Graben.

The survey of this area was conducted as a preliminary survey for sampling by boring machine system (BMS). But the drilling was prohibited by the deterioration of weather conditions and the cruise itinerary. Thus LC sampling was carried out at only one locality on the mound at the central depression of the central axial valley floor. The sample consists mainly of pyrite with some marcasite showing the characteristics of the low temperature hydrothermal deposits.

Chapter 4 Survey Results of Area 2

4-1 Outline of the Fiji Fracture Zone

The outline of the geologic structure of the Fiji Fracture Zone (FFZ) is shown in [Figure 4-1-1](#).

FFZ consists of intermittent depressions and oceanic ridges extending from the central part of NFB through north of the Fiji islands to the Tonga Trench, and includes Fiji Transform Fault (FTF). Many shallow seismic activities are observed along the FFZ (Louat and Pelletier, 1989), and the India-Australia Plate and the Pacific Plate are believed to be in contact through active fault (Hughes-Clarke et al., 1993).

The structure of the FFZ is not clear in some localities, but it forms a structural zone extending eastward from the Triple Junction, through north of Viwa Rift and Fiji Platform forming the northern boundary to the Lau Basin, and reaching the Tonga Trench. It is 1,000 ~ 1,200km long in the E-W direction. The topographic structure is clearly observed from 175°E to 179°E, and troughs such as Yasawa Trough and Yadua Trough, and topographic highs such as oceanic ridges are observed. The structure is not clear to the west of 175°E and to the east of 179°E.

From the results of the analysis of the shallow earthquakes along the FFZ, the zone between the Triple Junction and north of the Fiji Platform is concluded to be left lateral fault (Hunmburger, 1987; Louat and Pelletier, 1989). Pull apart structure (extensional relay zone) was formed in association with the left lateral movement and the spreading axes between Yasawa and Yadua Troughs at 177°30' E and at 178°30' E. These are called ERZ A and ERZ B (Fox and Gallo, 1984, Johnson and Sinto, 1990).

To the north of the Fiji Platform, oceanic ridges such as Balmoral, Braemer, and Bligh occur on the northern side of the FFZ. These ridges occur either parallel to or oblique to FFZ. These are considered to have had been a part of the Fiji Platform and separated by the movement of the ERZ B spreading axis (Jarvis et al., 1994).

4-2 Seafloor Topography and SBP of Area 2

(1) Seafloor topography and SPB

Seafloor topographic map, hillshade map, and three-dimensional map are shown in [Figures 4-2-1, 4-2-2, and 4-2-3](#).

This area has a conspicuous E-W trending topography consisting of troughs such as Yasawa and Yadua and oceanic ridge-type topographic highs. In addition to it, N-S trending valley topography consisting of Viwa Rift and ERZ A is observed.

The structure of FFZ between the Triple Junction and the Viwa Rift at 176°E is not very clear. A graben, 30km wide, extends for about 70km northeastward from the Triple Junction and topographically fades out at 174°30'E. From this point, a steep cliff extends in the southeastern direction at right angles to the graben and is cut off by northeast trending oceanic ridge near 175°00'E.

The present survey was carried out in an area to the east of the western end of the northeast trending oceanic ridge group.

Between 175°00'E and 175°40'E, ridges reaching 1,000m water depth or higher extends intermittently in the SW-NE direction forming topographic highs. This ridge topography gradually bends eastward from near 175°40'E and becomes aligned in the E-W direction. Balmoral Ridge extends in the NNE-SSW direction to the north of the above bend. Many lineaments are found to occur generally parallel to or somewhat obliquely to the ridge topography. To the east of 175°20'E, the crest line has many reliefs, but the ridges are relatively linear.

Between near 175°40'E and 177°15'E, the topography is clear with E-W axis consisting of E-W trending ridges and Yasawa Trough, and ridge-type topography on both northern and southern sides of the trough. The maximum relative height of the Yasawa Trough exceeds 4000m from the highest summit of the ridge on the northern side at 140m depth to the deepest part with 4500m depth. The slope indicating the outline of the Yasawa Trough is linear.

Near 176°10'E, the oceanic ridge continuing from the west is cut by valley topography. This valley extends southward from this point with relative depth of about 700m, and is called Viwa Rift. This is believed to be a spreading axis (Chase, 1971), and many horsts and grabens are observed nearby. They extend in the N-S direction along the rift axis.

From 177°30'E, a notable trough and a parallel oceanic ridge extending in the E-W direction over the easternmost edge of the survey area at 178°E are observed. The deepest part of the trough exceeds 4,000m in depth, and the relative depths to the ridges on the northern and southern sides are 1500~2,500m. This trough is called the Yadua Trough and constitutes the most notable structural element of FFZ together with Yasawa Trough. These two troughs extend in the E-W direction and they are separated about 25km at 176°25'E in the N-S direction. A topographic high of 2500m water depth is

observed between the two troughs, and ridge and valley topography with N-S trending axis is seen on the high centered around 177°25'E. As a result of the left lateral movement of the FFZ, a small-scale spreading axis which is believed to have pull-apart structure was formed and is called the Extensional Relay Zone (ERZ) (Johnson and Sinton, 1990). The axis of the ridge and valley structure gradually bend to the E-W direction at the northern and southern end and it largely has a "S" shape.

Yadua Ridge extends in the E-W direction sandwiched between the Yadua Trough and the Central Trough to the north of the Yadua Trough. This ridge is considered to be a fragment of the Fiji Platform (Jarvis et al., 1994).

(2) SBP survey

The SBP records of this area is not very good because the topographic relief is high and steep. Sediments covering the basement, however, are described for areas where these records were obtained.

The SBP records are largely divided into the following three groups ([Figure 4-2-4](#)).

Type 1: Alternation of transparent (unconsolidated sediments) and opaque layers is observed.

Type 2: Homogeneous opaque layers are observed. The boundary with the basement is relatively clear.

Type 3: This type is characterized by granular opaque parts without directionality. This occurs on slopes, and the nature of the record could be caused by the characteristics of the equipment.

It is seen from the SBP-type distribution map that Type 3 occurs in almost all of the survey area, followed by Type 2 which occupies about 20% of the area. Type 1 is seen only in small amounts in basin topography. The blank parts of the figure are areas with steep topography and the SBP records are not clear. It is believed that either sediments do not exist or are of Type 3.

SBP-type distribution of the western area is shown in [Figure 4-2-5](#).

Sediment layers of Types 1, 2, and 3 are observed and the thickness reaches 20~40m in some places at; the northwestern part of the survey area namely the ocean basin at the northernmost 175°11'E ~

175°33'E, the basin in the southern half of the central part of the survey area 175°35'E ~ 176°01'E, and the relatively flat basin in the southwestern end of the present survey area. Type 1 is only observed in the flat zone even in the basins. Almost all other parts of the survey area are covered by Type 3 or 2 sediments.

The southern sides of the following two oceanic ridges are particularly steep cliff and the zones are expressed in blank on the map and sediments are considered not to exist. These ridges are those extending eastward from 175°40'E, 16°37'S to 176°00'E, 16°35'S, and from 176°10'E, 16°30'S to 176°27'S.

The distribution of the SBP types of the eastern area is shown in [Figure 4-2-6](#).

In this area there are, also, blank zones without sediments from the ocean ridges to the steep southern cliffs in the southwestern part, and from the ridges to the steep slope in the eastern half of the eastern area. On the other hand, 2~3 cm thick Type 3 or in some places Type 2 sediments occur in the relatively flat parts of N-S Valley in the central part of the area, and in Yasawa Trough in the southwest and Yadau Trough in the northeast. Small amount of Type 1 sediments are only seen in the southern edge of the eastern part of the area at 177°54'E.

(3) MBES acoustic reflection intensity images

The acoustic reflection intensity images of Area 2 are shown in [Figure 4-2-7](#).

The acoustic reflection intensity level is high in the shallow zones at; the southwestern end of the survey area, ridges along the transform fault, and in the zone around the N-S trending ridges. Thus it is believed that either bedrock is exposed or the sediments are thin in the above zones. Although not shallow topographically, many horsts and grabens at the Viwa Rift also show very high acoustic level.

The acoustic reflection intensity level is relatively high in the basin at the eastern part of the Central Hill in the northwestern margin of the survey area and the trough to the south of it. These are under deep waters but the amount of unconsolidated sediments is believed to be small. The characteristics of each marine area will be reported below.

175°E ~ 176°30'E

Acoustic reflection intensity level is high largely in shallow zones such as plateaus and ridges, and

is low in deeper zones such as graben-like structures and basins. The important high zones are; the shallow zone in the southwestern margin of the survey area, the ridge along the NE- trending transform fault continuing to 175°45' E, and the ridge branching out from the above to the EW direction. It is inferred that exposed rocks are widely distributed in the above zones. The acoustic reflection intensity is also relatively high in the topographically shallow zones above 2,000m water depth, and the sediments are considered to be less developed.

Many topographic highs and troughs occur along the axis of the Viwa Rift which extends in the S10°W direction from the western end of the Yasawa Trough near 176°10'E. Here high acoustic reflection intensity is observed along topographic highs although it is not shallow as previously zones.

176°54'E ~ 178°00'E

The acoustic reflection intensity in this area also is, on the whole, high in the shallow zones such as plateaus and ridges and low in the deeper parts such as troughs and basins. The noted high acoustic pressure zones are; ridges extending in the SW direction in the southwestern part, around the NS Ridge, and ridge extending in the W-E direction from the Central Hill. The development of unconsolidated sediments is considered to be low in these parts of the area. The acoustic pressure is particularly high around NS Ridge, and bedrock is probably exposed extensively.

The acoustic reflection intensity is also relatively high in the basin in the eastern part of the Central Hill in the northwestern part of the area and the Yadua Trough. These are deeper zones, and lava and other hard rocks are considered to cover them. On the other hand, the zones where the acoustic level is low in spite of relative shallowness are; insular shelf at the southeastern edge and the ridge extending in the SW-NE direction to the northwest of the shelf.

4-3 Magnetic Survey

4-3-1 Total intensity

Total magnetic intensity was measured in the 175°E ~ 178°E zone, simultaneously with topographic survey with track line interval of 2nm. Effect of magnetic storm was not observed during the survey. A total magnetic intensity map was prepared by plotting the measured values on 500m grid. The contour interval was 20nT.

The total magnetic intensity of this area ranges from 41,550nT to 43,400nT, and it is generally higher in the south and lower to the north. This trend agrees with the theoretical trend of the global magnetic field (IGRF).

4-3-2 Magnetic anomalies

Magnetic anomalies were obtained as the residual value of the total intensity values measured over the track lines and International Geomagnetic Reference Field (IGRF) values. Grid conversion by minimum curvature method was carried out on the obtained magnetic anomalies. The magnetic anomaly map is shown in [Figure 4-3-3](#).

In general, the magnetic anomalies reflecting the existence of magnetic bodies in middle latitude areas are expressed as pair of negative and positive magnetic anomalies. In the southern hemisphere, negative magnetic anomalies occur on the southern side of the magnetic bodies and the positive anomalies on the northern side, and this is called normal magnetization, on the other hand when the positive and negative anomalies occur on the opposite sides it is the reverse magnetization. In the survey area, reverse magnetization is not observed from the magnetic anomaly map, almost all are normal magnetization. As a general tendency of this area, positive and negative anomalies occur along the spreading axis and the transform fault. The particularly conspicuous normally magnetized anomalies occur at the following three localities.

- (1) SW-NE trending ridge at the western end of the area.
- (2) Northern end of the Viwa Rift.
- (3) Flat zone between the Central Hill and N-S Ridge.

Of the above, (2) and (3) are not in topographically high zones, and the existence of highly magnetized body in the sub-seafloor zones are inferred.

4-3-3 Anomalies of reduction to the pole

In the middle latitude of the southern hemisphere, magnetic anomalies reflecting normally magnetized (magnetization in the same direction as the present earth) bodies are generally expressed by

high anomalies in the north and low anomalies in the south. By reducing to the pole, the high anomalies in the north migrate southward, and they are expressed as single high anomalies with the extinction of the southern low anomalies.

Maps of magnetic anomalies reduced to the pole show high anomalies immediately above normally magnetized bodies, and enable accurate correlation with topography and geology and with the interpretation of the distribution of magnetized bodies. Also by these maps, clarification of the magnetic structure using three-dimensional quantitative analysis becomes possible.

The three components of geomagnetism at the four corners of the survey area are as follows ([Table 4-3-1](#)).

Reduction to the pole was carried out in this work based on the following values.

Total magnetic intensity:	42,500nT
Inclination:	37.5°S
Declination:	12.3°W

The result of reduction to the pole on IGRF residual map is shown in the reduction to the pole anomaly map of [Figure 4-3-2](#). The distribution of the magnetic anomalies in reduction to the pole anomaly map has the following difference to that of the IGRF residual map ([Fig. 4-3-3](#)).

- Contrast of the magnetic anomalies is greater.
- The correlation between reduction to the pole magnetic anomalies and seafloor topography is not clear for the whole survey area.
- The magnetic anomalies reduced to the pole range from -779 nT to 1,112 nT and the variation of the reduction to the pole anomalies is large as a whole.
- As the positive anomalies migrate southward, the area of the positive anomaly distribution increases and that of the negative anomalies decreases. The values of the positive anomalies also increase.

The characteristics of the reduction to the pole anomaly distribution are mentioned below by dividing the survey area into Eastern, Central and Western Seas. On the composite map (Fig. 4-3-4) including the reduction to the pole anomalies, intensity of magnetization, and seafloor topography, the anomalies are numbered for each sea area so that the relation between the seafloor topography, and the reduction to the pole anomalies and magnetization anomalies is clear.

Eastern Sea

This sea area has the smallest variation of the reduction to the pole anomalies within the three sea areas. The N-S is the dominant direction of the linear occurrence of the reduction to the pole anomalies in this sea area. E-W trend is strong with IGRF residual anomalies, but this trend is very weak with reduction to the pole anomalies.

Positive reduction to the pole anomalies is distributed in the central part and the northeastern edge of the area. Negative anomalies occur in other parts of the area. In the eastern and western sides of this area, ridges and troughs with E-W trend are dominant on the seafloor, but the variation of reduction to the pole anomalies is very small and directional trend of the anomalies is not observed in these parts.

The trend of occurrence of the positive reduction to the pole anomalies (E05, E06, E07) in the central part of this area is mainly N-S. These positive anomalies correspond to southern Central Hill and the topographic high of the NS Ridge.

The relatively weak positive reduction to the pole anomaly (E02) in the northern end of the central part is located at the depression at the western edge of the Central Trough. At the eastern margin of this group of reduction to the pole anomalies, E-W system of positive reduction to the pole anomalies (E03), also, occur corresponding to the E-W trending small-scale topographic high in the Yadua Trough.

Positive reduction to the pole anomaly (E01) at the northeastern edge of the area coincides with the topographic high at the eastern end of the Yadua Ridge. The ridge extends to the west, but the extension of the anomaly differs and tends to extend in the northwest direction.

Central Sea

In this area, variation of the reduction to the pole anomalies is of medium level within the three sea areas.

The IGRF residual anomalies occur with dominant E-W trend, and this directional trend is also observed in the reduction to the pole anomaly map, but the dominant trend is N-S.

Positive reduction to the pole anomaly (C03) occurs on the Viwa Rift on the southern side of the Yasawa Trough, and this anomaly tends to extend to the south (C09) and east (C12, C13).

In the depression at the western edge of the Yasawa Trough, positive reduction to the pole anomalies (C01, C02) occur aligned in the E-W direction and extend westward. These anomalies tend to continue to the

anomalies of the Viwa Rift in the south.

In this area, correlation of the reduction to the pole anomalies and seafloor topography is not observed with the exception of the positive anomalies at Viwa Rift (C03) and that (C05) at the western end of the area.

Western Sea

The anomalies of this area have the largest variation within the above three sea areas.

In this area, the NE-SW direction which is dominant in the IGRF residual magnetic anomaly map is also strong for the alignment of the reduction to the pole anomalies (W01, W02, W04, W06, W11, W13). In the reduction to the pole anomaly map N-S (W03) and WNW-ESE systems of positive anomalies obliquely intersecting the above is also observed.

The positive reduction to the pole anomalies are distributed in the topographic highs and correlation with topography is good in this area.

4-3-4 Distribution of magnetization

Magnetization was analyzed by using the reduction to the pole magnetic anomaly map. A three-dimensional model consisting of aggregate of infinite amount of prisms approximated magnetic bodies under the seafloor and the magnetization of each prism was obtained by inversion method.

For the analysis of magnetization distribution, seafloor topography was used and three-dimensional model was constructed by dividing the subsurface zone into prisms with constant interval (upper limit of the prisms was fixed by the sea-level altitude of the seafloor). Next, total sum of the values of the reduction to the pole magnetism of all the prisms for a fixed area around a grid point were calculated and it was used as the grid value. These calculated values were compared with the reduction to the pole anomaly data and the calculation was repeated until the anomaly and calculated values converged. Thus the magnetization of all prisms was obtained and magnetization map was prepared. The effect of Curie temperature isothermal surface was eliminated by setting the bottom of the prism at 20km, namely the depth of Curie temperature.

Magnetization map prepared from the above method is shown in [Figure 4-3-5](#). This map was prepared by changing the magnetization of each prism, and thus it should be noted that the weight of the magnetization intensity is on the shallow subsurface parts. General tendencies are:

- The magnetization intensity of this area ranges from -3.1 to 3.1A/m, and the variation of the intensity is relatively strong in this area.
- The magnetization varies the most in the Western Sea, and the variation tends to decrease eastward.
- Intensity of magnetization is also stronger in the west and tends to decrease eastward.

The magnetization in the area from the Eastern Sea to the western edge of the Yasawa Trough in the Central Sea do not correspond to the large directionality of the seafloor, but corresponds to the trend of small ridges and seamounts. The positive magnetization anomalies also occur in the depressions at the western edge of large troughs in all sea areas.

In the area from western edge of the Central Sea to the Western Sea, the distribution of positive magnetization agrees with the highs of the seafloor topography, and it is indicated that the magnetic structure is different from that of the eastern part of the Survey area.

The characteristics of each sea area are as follows:

Eastern Sea

Magnetization ranges from -2 ~ 2A/m, and variation is small in this area.

Positive magnetization zone occurs extending in the southwestern direction in the central part, and they coincide with the topographic highs (Central Hill, N-S Ridge) with the exception of the positive anomaly of magnetization in the northern end. There is positive anomaly of magnetization elongated in the E-W direction at the eastern edge of the central magnetization zone, and this anomaly coincides with the east-west trending topographic high of the seafloor. On the other hand, the positive magnetization anomaly at the northern edge of the Central Trough is correlated to a topographic depression.

Positive anomaly of magnetization is observed at the topographic high at the eastern edge of the Yadua Ridge in the northeast, but the Yadua Ridge extends in the E-W direction while the positive magnetization anomaly extends in the NW direction obliquely crossing the ridge.

Negative magnetization zone which is widely distributed on the eastern side of the Eastern Sea (Central Trough ~ Yadua Ridge ~ Yadua Trough) is more than $-2A/m$. This is believed to reflect the fact that the whole negative magnetized zone is not reversely magnetized but either magnetization is almost nil or very weak.

Central Sea

Magnetization in this area ranges from $-1.6 \sim 3.1A/m$ and the degree of variation is intermediate of the three sea areas.

The positive anomalies of magnetization occur dominantly in the E-W direction, and the alignment changes direction in the south to N-S.

With the exception of the two positive anomalies at the western end of the Yasawa Trough in the central part, groups of positive anomalies of magnetization (near Viwa Rift and western edge of the area) occur on topographic highs, indicating correlation with seafloor topography.

The negative magnetization zone of this sea area is the narrowest of the three sea areas, and as with the Eastern Sea, the whole negative magnetization zone is not necessarily reversely magnetized, but it is an indication of almost nil or very weak magnetization.

Western Sea

The degree of variation of magnetization of this sea area is the largest of the above three sea areas, ranging from $-3.1 \sim 2.8\text{A/m}$.

The groups of magnetization anomalies of this area occur aligned dominantly in the NE-SW direction, and groups of positive anomalies of magnetization are distributed obliquely to the above in the N-S and NW-SE directions. In the western part, groups of positive anomalies of reduction to the pole magnetism are distributed in the topographic highs, and correlation with the topography is the best in the three sea areas.

Large negative anomalies of magnetization of -3.1A/m occur in the central-northern part of the Western Sea, and this is considered to be caused by the negative reduction to the pole anomaly formed by the calculation of the reduction to the pole anomalies. Therefore, reverse magnetization has not occurred near the zone, but is believed to indicate that the magnetization is very weak or nil.

4-3-5 Magnetic structure map

The magnetic structure map laid out in [Figure 4-3-6](#) shows the following structures, which were inferred from the reduction to the pole anomaly map ([Fig. 4-3-2](#)) and magnetization map ([Fig. 4-3-5](#)).

- (1) Ferromagnetic bodies exposed or buried in shallow subsurface parts:
Normally magnetized ferromagnetic bodies exposed on the seafloor and the areas of those buried in shallow subsurface zones.
- (2) Magnetic lineaments:
Lines joining continuous positive reduction to the pole anomalies.
- (3) Extremely weakly magnetized zones:
Zones where magnetization is nil or extremely weak.

The characteristics of the magnetic structure of Figure 4-3-6 are as follows.

- (1) Banded patterns are not observed in this survey area at present.

- (2) Magnetic anomalies indicating reverse magnetization have not been found.
- (3) The occurrence of ferromagnetic rocks are dominantly aligned in the N-S direction in the Eastern Sea, but E-W ~ NE-SW alignment is dominant in the Central to the Western Sea.
- (4) The correlation between the distribution of ferromagnetic rocks and topographic highs are totally different in the western and eastern parts of the survey area. In the west, ferromagnetic rocks occur on topographic highs such as rifts and ridges showing good correlation with seafloor topography. On the other hand, in the east, the correlation between the occurrence of ferromagnetic bodies and topographic highs is low with the exception of small topographic highs such as the Central Hill, NS Ridge, and Viwa Rift.

Chapter 5 Investigation of Hydrothermal Activities

5-1 Extensional Relay Zone (ERZ)

From the topographic survey of the Fiji Fracture Zone (FFZ), occurrence of hydrothermal activities was considered to be highly probable in the following three areas:

- Viwa Rift with rifting topography
- ERZ A between Yasawa Trough-Yadua Trough
- Central Hill to the north of ERZ with fracture topography in the same direction as ERZ

It is believed from the acoustic reflection intensity images that the sediments are thinnest on ERZ A followed by Central Hill and Viwa Rift. Thus the present hydrothermal survey was carried out in ERZ A and Central Hill.

The locations of SSS and FDC surveys and sampling conducted in the ERZ A are shown in [Fig. 5-1](#).

5-1-1 Topography of ERZ A

As mentioned earlier, ERZ A is a spreading topography formed by the discrepancy of the FTF movement, which was observed in Yasawa and Yadua Troughs. Cruise SO-35 of R/V Sonne was carried out to the north of this area including Braemer Ridge and a basalt sample containing pyrite was collected.

Seafloor topographic map, hillshade map, and bird's eye view are laid out in [Figures 5-1-1, 5-1-2](#) and [5-1-3](#), and also MBES acoustic reflection intensity map in [Figure 5-1-4](#). This seafloor topographic map covers an area from the eastern edge of the Yasawa Trough in the west to the western edge of the Yadua Trough in the east, and from the Central Ridge in the north through Central Basin, Yadua Ridge, Yadua Trough to the southern slope of the Fiji Island Platform in the south.

In the northern and southern parts of the mapped area, there are depressions of about 2,700m depth connected to Yasawa and Yadua Troughs, and gentle topographic high of 1,800m depth exists near the central part adjacent to the Fiji Platform, and above this high, there are several ridge-valley structures with 400 ~ 600m relative height (relative depth). Within the mapped area, four pairs (eight rows) of ridge - valley system is confirmed to extend in the N-S direction around the valley at 16°36'S, 17°24'E. The steepest valleys occur on the western side, but the ridges become shorter away from the center and continuity becomes poor.

The axes of the ridge - valley system bend east or westward at the northern and southern ends, and connect to the Yasawa or Yadua Troughs through the above depression.

N-S Valley consisting of depression around 16°35'S, 177°24'E and the E-W extending ridge has a stairstep topography and is composed of three to four terraces. These terraces are wider on the western side. Small hilly topography occurs aligned in the N-S direction on the floor of the valley.

The MBES acoustic reflection images show strong reflection intensity at the N-S Valley in the central part indicating comparatively thin sedimentary cover here and in the depression to the north and south.

5-1-2 SSS survey

Sediments are thin in the central part of the N-S Valley, which is located at the valley-ridge topography believed to be a rift structure. A basalt sample containing pyrite has been collected from here during the past surveys. Thus it was decided to carry out SSS survey in the vicinity of the N-S Valley. The survey was made on three track lines. One 9nm long line was over the valley floor; another was 3nm across the depression on the terrace of the western slope, and the other passed over the ridge (N-S Ridge) on the steep eastern side over a length of 4.5nm.

A SSS mosaic is laid out in [Figure 5-1-5](#).

The SSS results indicate that the entire valley is generally exposed or the overlying unconsolidated sediments are thin. Particularly near 16°22~24'S at the valley floor, linear structures are very few, and the reflection intensity is homogeneous and strong indicating the possibility of lava flow existence. The southern side of the valley floor has slightly less reflection intensity and thus thicker sedimentary cover is inferred. N-S trending linear structure considered as fractures are clearly observed along the topographic alignment in all track lines. Many of these lineations are seen on the southern side of the valley floor and on the western terrace.

Near the northern end of the valley floor track line, knoll to mound type topographic highs occur near 16°24'S on the valley floor and near the summit of the N-S Ridge near 16°26'S. Slightly more sediments occur on these mounds with the exception of those near 16°24'S on the valley floor.

5-1-3 FDC observation

FDC observation was carried out along the following five track lines ([Fig. 5-1-6](#)).

- Track line FDC08 extends from the lowermost western terrace of the northern floor of the N-S Valley, through the deepest depression, and to the lowest part of the eastern slope.
- Track line FDC 11 extends from the lowermost part of the western slope, through the deepest depression, small knoll within the depression, lowest part of the eastern slope, terrace surface, and N-S Ridge slope, to the summit of the N-S Ridge.
- Track line FDC 09 extends on the eastern side of the deepest depression on the southern side of the N- S Valley floor along the axis of the depression.
- Track line FDC 10 extends over two small hills on the northern side of the N-S Valley floor.
- Track line FDC 14 extends along the bathymetric contour at the base of the terrace in the middle part of the slope from the N-S Valley floor to the ridge summit.

By the above survey, discoloration of the bottom sediments considered to be caused by hydrothermal activities was found at the following localities. Slope of the small knoll in the deepest depression (FDC11), upper part of the lower slope on the eastern side and the middle slope (FDC08, 11), and base of the terrace in mid-slope from the valley floor to the ridge (FDC11, 14). The above localities are shown in [Figure 5-1-6](#), surface geology in [Figure 5-1-7](#), distribution of fissures and cliffs in [Figure 5-1-8](#), and distribution of organism in [Figure 5-1-9](#). The cross sections of N-S Valley along the N-S direction (FDC09) and E-W direction (FDC11) are shown in [Figures 5-1-10](#) and [5-1-11](#), respectively.

Topography and geology

The results of observation along the above track lines are as follows.

Track line FDC08: Fractures running in the N-S direction were observed on the lowest terrace on the western side of this track line in the northern part of the survey area. But cracks and small cliffs were hardly observed in the deepest depression. Sheet lava occurs on both the western lowest terrace and the deepest depression and pillow lava covers this sporadically. Pillow lava is observed continuously particularly on the western lowest terrace and some are spherical. On the lowest slope of the eastern side of the N-S Valley is covered by sheet lava, and the upper part of the lowest slope is covered by sheet and massive lavas. Unconsolidated sediments are somewhat thick on the western part of the lowest terrace on the western side, but these loose sediments were hardly observed in other parts of this area.

Track line FDC09: This track line runs in the N-S direction along the axis at the eastern edge of the deepest depression. Fractures and cliffs in the N-S direction were observed in the bottom of the depression. The cliffs are essentially steep with relative height of several meters, but many of them have apparent gentle slope because of talus cover. Pillow lava is generally observed on the seafloor, the pebbles covering the small cliffs consist of sheet lava and pillow lava.

Track line FDC10: Two small knolls in the northern part of the deepest depression were observed by this line. They were found to be covered by pillow lava. The slope of these knolls are generally gentle, but small cliffs extending in the N-S direction are seen in some localities.

Track line FDC11: Cracks and small cliffs were hardly observed from the western lowest terrace to the deepest depression and sheet lava is distributed as in the case of FDC11, and pillow lava occurs partly. Mixture of sheet lava and pillow lava pebbles are, also, observed in some localities. The small hills in the deepest depression consist of steep slopes and relatively flat summit. Sheet lava and massive lava occur from the slope to the summit. But sheet and pillow lava pebbles occur on the base of the slope. The eastern lower slope is steep and is wholly covered by pebbles. The pebbles are mainly sheet lava and pillow lava pebbles are rare. The terrace is generally flat with some pebble-covered protrusions with several meters relative height. North-south trending fractures occur at the peripheries of the terraces and at the base of the upper slope. The upper slope is steeply rising from the terrace with N-S trend and consists of sheet and massive lavas. Continuous pillow lava distribution was observed on the summit of the N-S Ridge.

Track line FDC14: Sheet lava pebbles occur on the terrace plane in this track line. Some relieves are found, but small cliffs are not observed. Sheet lava is observed at the upper slope, but some pillow lava pebbles are found mixed with sheet lava pebbles on the base.

The above is summarized as follows.

Fractures and small cliffs are hardly observed at the deepest depression in FDC track lines 08 and 11, and the surface of the depression is covered sporadically by cylindrical or spherical pillow lava. Unconsolidated sediments are almost non-existent on this depression, and it is concluded that young new magmatic activity occurred exuding a large amount of lava forming pillows. On the other hand, at the periphery of the depression, N-S trending fractures and small cliffs of several meters relative height are observed and pillow lava is distributed. Faults with N-S strike are believed to be developed between the deepest depression and the lower slope, and pillow lava activities are considered to have occurred along the associated fractures.

On the slopes from N-S Valley to the N-S Ridge in the east, many steep slopes rise directly from the floor. Corresponding terraces are found on the western side of the N-S Valley, and the most conspicuous terrace is observed around 1,900~2,000m depth. The lowest part of the slope from the floor of the deepest depression to the terrace is covered by sheet lava, and the upper part of this slope is covered by massive lava. The upper slope from the terrace to the N-S Ridge consists of linear steep cliff trending in the N-S direction and consists of sheet lava and massive lava. Pillow lava occurs continuously on the summit of the N-S Ridge. The terrace surface is generally flat with some protrusions with relative height of several meters covered by brecciated sheet lava. Fractures trending in the N-S direction is observed on the terrace periphery and the base of the upper slope in Track line FDC11. There are unconsolidated sediments in some localities, but they are thin. This slope is believed to be a fault scarp from the fact that N-S trending cracks are observed near the boundary between the terrace periphery

and the base of the upper slope, and that the slope forms a steep cliff in the N-S direction.

Alteration and mineralization

The alteration of rocks observed by FDC are shown in [Figure 5-1-6](#).

Discoloration of exposed surfaces rocks, pebbles, and sediments was observed at; the middle slope of the lower step below the terrace of the western slope of the N-S Ridge on FDC08, from the upper part of the lower step to the terrace periphery of FDC11, and the base of the upper step slope near the intersection of FDC11 and FDC14. On FDC11, a discolored pebble was confirmed to occur at one locality on the slope of a knoll in the deepest depression. The discolored parts are dark brown to reddish brown, and are all spots of several tens of centimeters across.

The discoloration on the slopes of the knolls in the depression of FDC11 and on the lower slope of FDC08 occurs only locally, but it occurs in a relatively wide range on the terrace periphery and base of the upper step of FDC11.

Distribution of organisms

Lithophytes such as sponges and gorgonarians are generally present, relatively wide distribution of benthic organisms such as sea cucumbers and star fishes were also observed. The distribution was not particularly dense, but lithophytes such as sponges and gorgonarians were present at ten and several meters intervals in all track lines.

5-1-4 Water temperature anomalies

Water temperature was measured at accuracy of $1/500^{\circ}\text{C}$ by CTD attached to FDC and temperature anomalies were extracted after considering the variations of water temperature due to the water depth. The distribution of the water temperature anomalies is shown in [Figures 5-1-12](#).

By Track FDC11, temperature anomalies were observed at the western periphery of the terrace, base of the upper step slope, and the summit of N-S Ridge; and by FDC14 at the base of the upper step slope.

The anomalies at the terrace zone was particularly strong at more than 0.04°C, and the locations of the anomalies agree with those of the discoloration of the sediments or pebbles. At the ridge summit, the anomalies occurred over pillow lava. At the ridge summit, anomalies were also detected at two localities between 16°25' ~ 27'S by a thermometer attached to SSS-04.

Water temperature anomalies were detected on Track lines FDC10 and 09 where alteration and mineralization were not observed. On FDC10, a large anomaly of 0.02~0.04°C was detected on a knoll formed by pillow lava, and on FDC09, an anomaly of 0.01~0.02°C was recorded where pebbles of pillow lava were observed.

5-1-5 Results of sampling

Sampling was carried out at three sites, dredging at one locality and drilling at two. The localities are shown in [Figure 5-1-13](#) and columnar section of the drill cores in [Figure 5-1-14](#). Contents of the collected samples are listed in [Attached Table 3](#).

Dredging was done at a slope of a small hill where discoloration was observed by FDC 11 survey. It is located at the floor of N-S Valley and angular pebbles (7 ~ 15cm diameter) of basalt were collected. Although weathering is observed at surfaces, they are generally fresh. They are aphyric to microcrystalline and are mixture of porous and compact pebbles. Minute pyrite grains were attached in a pore of one of the samples. Black coarse sand was collected simultaneously. Black volcanic glass was observed microscopically and some quartz grains were mixed.

Drilling was carried out at two sites on middle slope of the ridge, and pebbles of basalt were collected at one site. They are aphyric and porous. Although discoloration is observed along some pores, they are generally fresh. Monitoring of the seafloor showed that seafloor was covered by pebbles with thin cover of pelitic sediments.

5-1-6 Results of laboratory tests

The dredged and drilled samples were examined by thin section microscopy, chemical analysis, Ar-Ar age determination, and x-ray diffraction. The results are reported below.

5-1-6-1 Thin section microscopy

Thin sections of the samples were studied in order to identify the constituent minerals and to confirm the degree of alteration of the rock. The numbers of examined samples were four, namely three dredged basalt and one drilled basalt samples. Cards with microscopic description of the samples are given in [Attached Table 5](#) and the observed constituent minerals are listed in [Table 5-1-1](#).

The three samples dredged are basalt with intersertal texture consisting of plagioclase, clinopyroxene, olivine, and volcanic glass. Although differences in the conditions of the pores and phenocrysts are observed by unaided eyes, significant differences are not found microscopically. These samples are all believed to have been formed by quenching of magma. The samples are either weakly weathered or not altered, and evidences of hydrothermal alteration are not observed.

5-1-6-2 Chemical analysis of rocks

Two samples, namely one dredged and one drilled, were chemically analyzed. The analyzed elements, limits of detection, and analytical methods are same as those shown in [Tables 3-6-2](#) and [3-6-3](#), respectively. Analytical results are shown in [Table 5-1-2](#).

Correlation of the analyzed elements is laid out in [Figure 5-1-15](#), [16](#), [17](#), [18](#), [19](#) and [20](#).

(1) Binary correlation diagram

A low Mg# ($\text{MgO}/(\text{MgO}+\text{FeO}^*)$) of the BMS04A (0.22) compared with that of CB03C (0.40) suggests that BMS04A was derived from somewhat differentiated magma. All the binary correlation diagrams do not deviate far from the magmatic differentiation trend, and thus it is inferred that both of the samples originated from the same magma.

(2) AFM diagram

Both samples (CB03C and BM04A) have a relatively high FeO compared with MgO, and are plotted near the boundary of tholeiite and calc-alkali series.

(3) Mn-TiO₂-P₂O₅ diagram

CB03C sample is plotted in the mid-oceanic ridge basalt (MORB) area, while BMS04A at the boundary of MORB, oceanic-island tholeiite (OIT), and oceanic-island alkali basalt (OIA) areas.

(4) Spiderdiagram of HFS and LIL elements

Samples CB03C and BMS04A have almost the same HFS (high field strength element) and LIL (large ion lithophile element) values indicating that the samples originated from the same primary magma. The spiderdiagram pattern and values of CB03C are similar to those of MORB. Sample BMS04A also show pattern similar to that of MORB and back arc basin basalt (BABB). The LIL

values of the samples are high and are closer to BABB than MORB.

(5) Chondrite-normalized patterns of rare earth elements

Both CB03C and BMS04A samples show flat pattern rich in LREE and HREE. CB03C pattern tends to rise rightward similar to N-MORB, while BMS04 tends to decrease to the right similar to the patterns of BABB and P-MORB.

(6) Zr-Nb-Y diagram

Both CB03C and MBS04A samples are plotted in the N-MORB and IAB areas in this diagram.

As a result of chemical analysis, sample CB03C can be classified as MORB. The trace elements, rare earth element contents and ratios are both very similar to N-MORB. BMS04A, on the other hand, although is similar to CB03C in binary correlation diagram, LIL values are higher than those of MORB and the pattern of the chondrite-normalized diagram of rare earth elements resemble that of BABB, and thus the possibility of this sample being BABB is high.

5-1-6-3 Ar-Ar age determination

The age determination of basalt by Ar-Ar method was conducted for two samples of CB03C and BMS04A which were, respectively, collected at the deepest depression and on the eastern terrace of the N-S Valley. The results are shown in [Figure 5-1-21](#).

The obtained ages are 16.0 ± 10.2 Ma for CB03C and 3.0 ± 8.3 Ma for BMS04A. The results show a high error range of low reliability. The reason for this is due to a poor K_2O content of less than 0.5% in both of the basalts, and it was impossible to extract enough ^{40}Ar to obtain reliable $^{40}Ar/^{39}Ar$ ratios for the age determination.

5-1-6-4 Results of x-ray diffraction

X-ray diffraction analysis was carried out on four samples, three samples of CB03 and one BMS04 sample. The results of X-ray diffraction are shown in [Table5-1-3](#), and X-ray charts in [Attached Figure 5](#).

Peaks of only plagioclase were observed in CB03 samples and no other minerals were found by X-ray diffraction.

In sample BMS04, small amount of potash feldspar was found besides plagioclase.

5-1-6-5 Summary of experimental results

From chemical studies it was clarified that both CB03 and BMS04 samples are basalt and that they originated in the same MORB-type magma which had differentiated to a small degree. If they are from the same magma, BMS04 with smaller Mg# is believed to have had differentiated more than CB03.

By thin section microscopy, the conditions of phenocrysts and texture indicate that both samples are basalt quenched from magma. The state of the phenocrysts shows that BMS04 was more severely quenched than CB03.

In thin sections it was observed that some of the olivine had decomposed to iddingsite in Sample A of CB03, and small amount of carbonate minerals was found in Sample C, but the alteration of the samples are considered to be very weak.

5-1-7 Hydrothermal activity in ERZ A

The deepest depression was noted as a zone with high possibility of the occurrence of hydrothermal activities on the basis of the results reported by the Cruise Sonne 35 (Stackelberg et al., 1990 etc.). Thus, the deepest depression was surveyed together with the slope extending to the N-S Ridge on the eastern side.

FDC observation showed that the depression was totally covered by sheet lava indicating intense magmatic activities accompanied by the effusion of a large amount of lava. However, neither alteration nor discoloration of rocks and sediments was observed, and neither dense distribution of organisms nor water temperature anomaly was detected. Thus it was not possible to confirm evidences of intense hydrothermal activity.

On the other hand, water temperature anomaly of 0.01~0.02°C was detected near the boundary between the eastern edge of the deepest depression and the lower step slope (FDC09). FDC observation also showed the occurrence of fractures and small cliffs. Although hydrothermal organisms were not found, relatively dense existence of lithophytes such as sponges were seen. Thus it is possible that hydrothermal solution rose along the fractures and small cliffs at the eastern edge of the deepest depression.

Discolored rocks and sediments occur sporadically at the periphery of the lowest terrace of the western slope of the N-S Ridge and near the boundary between the middle terrace and the upper step slope, and water temperature anomalies are detected at these localities. Although pebbles and taluses are generally distributed in the vicinity of the above localities, the exposed bed rocks have N-S trending cracks. This is interpreted to indicate the possibility of hydrothermal activity under the pebbles and taluses.

The localities where hydrothermal activity was indicated by the present survey are near the boundary between the terraces and the slope with N-S trending cracks and small cliffs.

The topography of this area is considered to have been formed by spreading in the E-W direction associated development of normal faults of the N-S system and the resulting graben system. The slope between the terraces are faults and are considered to have been the conduits for hydrothermal solutions. The discoloration and water temperature anomalies were found during this survey at the following zones. They are; eastern edge of the deepest depression, periphery of the western lowermost terrace, near the boundary of the middle terrace and upper step slope, and the vicinity of the slope between the terraces. Therefore N-S trending faults are expected to occur in these localities and there are possibilities of hydrothermal activities through these faults. During the present survey, FDC observation was not carried out to the west of the N-S Valley. But the geologic environment of the western zone is considered to be similar to that of the eastern part, and survey of the part is desirable.

Water temperature anomaly was detected at the summit of the N-S Ridge, and mound-type topography is found by SSS survey, but sedimentary cover is believed to be thick in the area.

5-2 Central Hill Survey

5-2-1 Seafloor topography

Seafloor topographic map and other maps are shown in the [Figures 5-1-1](#), [5-1-2](#), [5-1-3](#) and [5-1-4](#) of the previous section.

Central Hill is at the northern extension of the N-S trending axis of ERZ A. The Central Hill is a knoll located to the north of the eastward bend of ERZ A which extends further towards the Yadua Trough. Yadua Ridge extends eastward continuously from the Central Hill and is located between two E-W trending troughs, namely the Central and Yadua Troughs on the north and southern sides.

The topography below 2,500m water depth continues to the Yadua Trough, but the Central Hill is an isolated knoll with a relative height of 500m from the saddle to the Yadua Ridge. The lateral outline is almost a regular triangle with the western, eastern, and southern slopes forming the sides. The western slope is steeply linear almost in the N-S direction and is parallel to the ERZ axis. The northeastern side generally consists of gentle slope and the depth gradually increases to the Central Trough with more than 3,500m of water depth. The southern slope is relatively steep above 2,850m depth, but the base is relatively flat and continues to the plateau-type topography of the periphery of the N-S Valley in the south.

The northeastern slope of the knoll is gentle and N-S trending creek topography is seen near the summit. Many topographic highs of several tens of meters in relative height and many small creeks are found on the gentle slope on the northeastern to the eastern side.

MBES acoustic reflection intensity is somewhat high on the knoll and unconsolidated sediments are considered to be thin. SBP records were not very clear due to the undulations of the seafloor, but it is believed that the exposure is generally good or the unconsolidated sediment cover was thin.

5-2-2 FDC observation

FDC survey was carried out along two track lines (FDC12, 13) in this area. FDC12 extended in the N-S direction over the ridge on the northeastern side of the summit and down along a creek, and FDC13 extended in the E-W direction over the ridge on the northern side of the summit and across the accumulation of shells confirmed by FDC12. Accumulation of shells was confirmed for about 300m in both FDC12 and 13.

The distribution of shells and other relevant material is shown in [Figure 5-2-1](#), and surface geology in [Figure 5-2-2](#). The distribution of organisms are laid out in [Figure 5-2-3](#).

Topography and geology

FDC12 and 13 profiles are shown in [Figures 5-2-4](#) and [5-2-5](#).

FDC12 shows a gentle profile down a creek from the ridge, and topographic highs of several tens of meters relative height are seen in the upstream parts and near the end of the track line at the intersection with FDC13. Generally the topography is gentle including the slopes of the topographic highs, but there are steep cliffs of several meters in height at several localities.

The eastern and western slopes of the knoll crossed by FDC13 are also generally gentle and undulations of several to several tens of meters are observed. Here again there are steep cliffs of several meters height are seen in several localities.

The steep cliffs are seen on the northern to northeastern slopes of the knoll, on the northern part of FDC12 and 13. N-S trending cliffs are dominant over the E-W trending ones, but E-W trending cracks are dominant on the eastern slope of the knoll on the southern side of FDC12.

The rocks similar to sheet lava are distributed throughout and these rocks are covered by pelitic unconsolidated sediments. The rocks similar to pillow lava occur near N-S trending fractures at the western end of FDC12 and on small ridge extending from the summit at the southern end of FDC12 southeastward.

Pelitic unconsolidated sediments are seen throughout the area and are generally thin.

Alteration and mineralization

Accumulations of white bivalve shell fragments were confirmed by FDC12 and 13. Shell fragments are distributed over a range of 700m on each track line, and particularly large accumulation continued for about 300m in both N-S and E-W directions.

In this particularly large shell fragment accumulation, some of the rocks and sediments were discolored to reddish brown. Near the central part of discoloration on FDC12, conical protrusion considered to be a part of a chimney was observed. The rocks in the vicinity of the bivalve shell fragment accumulation were sheet lava type rocks covered by unconsolidated sediments, and the sediments were thick.

Distribution of organism

The entire survey area is covered by pelitic sediments, and benthic organisms such as sea cucumbers and star fishes were widely observed. On the other hand, lithophytes such as sponges and gorgonarians were only sparsely observed with the exception of the vicinity of the summit. Particularly near the shell accumulations, organisms both lithophytic and benthic were almost non-existent and only a few gorgonarians were seen.

5-2-3 Water temperature anomalies

Distribution of water temperature anomalies is shown in [Figure 5-2-6](#).

Water temperature anomalies were found at six points and at five points large anomalies exceeding 0.04°C were recorded. Anomalies of 0.02°C and 0.06°C were recorded near the locality where chimney-type protrusion was observed in the discolored zone.

Water temperature anomalies exceeding 0.06°C were obtained in the creek on the eastern side of the summit. These are localities where E-W trending small cliffs and cracks are developed across the creek over sediment-covered or exposed rocks.

A notable anomaly of 0.08°C was recorded on the northern side of the knoll on FDC13. This locality is a saddle of a ridge extending northeastward, and N-S trending small cliffs are observed in the vicinity.

Accumulations of bivalve shell fragments were characteristic of the Central Hill, but large water temperature anomalies were not recorded in the shell accumulations with the exception of the locality where chimney type protrusion was found.

5-2-4 Sampling results

Sampling was carried out at localities where bivalve shells were accumulated, namely CB sampling at two localities, LC at one, and seafloor drilling at two. Samples were collected at all sites.

Sampling localities are laid out in [Figure 5-2-7](#), list of collected samples in [Appendix Table 3](#), and drill core columnar sections in [Figure 5-2-8 \(1\)](#), [\(2\)](#), and [\(3\)](#).

By CB sampling, gabbro, serpentine, dolerite, and limestone were collected besides bivalve shells. Manganese oxides were attached to the surface of the rocks and shell fragments.

Gabbro was collected by LC sampling.

By seafloor drilling, pebbly cores were collected at three sites and two among them contained bottom sediments. The rocks are basalt, serpentine, trachyandesite, and gabbro. The bottom sediments are calcareous clay, and at BMS01 about 8cm of black calcareous clay containing minute pyrite grains was collected.

5-2-5 Results of laboratory tests

Rocks, bottom sediments, and Mn oxides of the collected samples were tested and shells identified in the laboratory. The tests carried out are as follows.

Rocks: Thin section microscopy, chemical analysis, Ar-Ar age determination, X-ray diffraction

Bottom sediments: Microscopy, gravity separation, x-ray diffraction, microfossil identification

Mn oxides: Chemical analysis

Shell fragments: Identification, C14 age determination

The results of the above are reported below.

5-2-5-1 Thin section microscopy of rocks

Thin section studies were carried out with the purpose of identifying the constituent minerals and of clarifying the degree of weathering. A total of 15 samples were studied and they are; eight dredged samples, one LC, and six drill cores. Cards with microscopic description are laid out in [Appendix Table 2](#). The results of microscopic observation are shown in [Table 5-2-1](#).

Thin section studies show that the samples consist of ultra-mafic to mafic plutonic and hyabysal rocks such as peridotite (lherzolite), gabbro, and dolerite. Metamorphic rocks such as metagabbro, serpentinite, and metadolerite derived from the above are present. Unmetamorphosed trachyandesite and basalt were also found. Metamorphic minerals and cataclastic texture were found in all rocks of 13 samples with the exception of two gabbro samples, indicating episodes of metamorphism and tectonic movements.

5-2-5-2 Chemical analysis of rocks

Four samples, three dredged and one LC, were chemically analyzed. The analyzed elements, detection limit, and methods of analysis are the same as those laid out in [Tables 3-6-2](#) and [3-6-3](#). The analytical results are listed in [Table 5-2-2](#).

Correlation diagram of the analyzed elements are in [Figures 5-2-9, 10, 11, 12, 13](#) and [14](#).

(1) Binary correlation diagram

The three samples, CB01B, E, and LC06A, have large Mg# values exceeding 0.6, and they are believed to have derived from undifferentiated magma. All elements of CB01B and LC06A samples indicate differentiation from the same magma, and CB01E sample is also considered to be within the differentiation trend of this magma.

On the other hand, CB01A has low Mg# value of 0.27 and is believed to have been derived from differentiated magma. It is close to the group of basalts collected at N-S Valley. However, the trend of differentiation of the two groups differs in the binary correlation diagram. This probably is caused by the effect of alteration, and the identity of the origin of the magmas is not clear.

(2) AFM diagram

Samples CB01B, E, and LC06A are plotted in high MgO, low FeO area, while CB01A is plotted in low MgO, high FeO area similar to the basalt sampled at N-S Valley. These four samples, however, are plotted near the boundary of tholeiite series and calc-alkali series.

(3) Mn-TiO₂-P₂O₅ diagram

Three samples CB01B, E, and LC06A are plotted in the calc-alkali basalt (CAB), while CB01A is plotted at the boundary between MORB and IAT.

(4) Spiderdiagram of HFS and LIL elements

LIL elements are generally depleted in all samples. HFS elements which are less affected by weathering are also depleted in samples CB01B, E, and LC06A, and these are believed to have been derived from primary magma similar to island arc tholeiite.

CB01A is poor in LIL elements, but is rich in HFS elements, and probably was derived from primary magma similar to MORB.

(5) Chondrite-normalized diagram of rare earth elements

CB01A sample is rich in both LREE and HREE elements and show flat pattern with slight increase to the right, similar to N-MORB.

Samples CB01B and LC06A both are poor in LREE with right increasing pattern, while that of sample CB01E is flat. All three, however, are generally poor in rare earth elements, and similar to the pattern of tholeiitic basalt.

(6) Zr-Nb-Y diagram

All four samples are plotted in or close to the area of N-MORB and island arc basalt.

As a result of chemical analysis samples CB01B, E, and LC06A are classified as island arc basalt being depleted in HFS elements.

REE and HFS elements of CB01A sample are similar to those of N-MORB. The ratios of these elements are also similar to those of the basalt collected at N-S Valley.

5-2-5-3 Ar-Ar age determination

The age determination by Ar-Ar method was conducted for three samples CB01B, E, and LC06A, however, no reliable result was obtained due to very poor concentration of K, less than 0.10%, in these samples.

5-2-5-4 X-ray diffraction results

Of the 15 samples studied microscopically, X-ray diffraction examination was carried out on 12 samples, namely CB01A, B C, CB02A, B, E, and BMS01E, BMS02A, C, BMS03A. The results are shown in [Table 5-2-3](#), and the X-ray charts in [Appendix Figure 4](#).

Serpentine or chlorite peaks were observed in 11 samples out of 12 samples. Considering the results of the microscopic work together with x-ray diffraction, serpentine was produced from alteration of olivine. Only plagioclase peaks were observed and no other minerals were recognized in the three samples of CB03.

In BMC04 samples, small amount of potash feldspar was found besides plagioclase.

5-2-5-5 Results of microscopic study of bottom sediments

Smear slides were prepared for clay containing minute pyrite grains and clay immediately above and below this layer of BMS01. These slides were studied microscopically. Clay from BMS03 was also,

observed by microscope for reference. The samples are listed in [Table 5-2-4](#).

The prepared samples were observed by 100 magnification (eye piece and objective lens both 10 magnification). Open Nicoles and crossed Nicoles were used as necessary.

The descriptions are listed in Attached Table 4. The observed minerals are laid out in [Table 5-2-5](#).

The coarse-grained materials of all four sediments are mostly bones, needles and other remains of foraminifers and sponges.

Pyrite, observed during the sampling, are believed to have oxidized to limonite or iron sulfate, and was not observed microscopically in the smear slides. Pyrite altered to iron sulfate probably was leached out.

The amount of limonite in BMS01B sample in which pyrite was observed and was black is 2%. The content in sample A at a higher layer is 6%, while that of the lower layer, sample C, was 1%. Limonite was also found in BMS03 sample with a content of 3%, and the shape and grain-size are the same as BMS01.

The observed minerals were rock-forming minerals of mafic igneous rocks. They are mainly olivine, clinopyroxene, and orthopyroxene. Most of them are strongly altered to chlorite, serpentine, opaque minerals (iron titanates), and iddingsite. They are mostly close to idiomorphic with some rounding by transportation in seawater. Thus these minerals are considered to have derived from hypabyssal rocks (dolerite) formed by magma intrusion rather than from plutonic rocks (gabbro). Matrices containing volcanic glass were not observed.

Chlorite is brown, and opaque minerals oozed out in threadworm-form on altered olivine. These phenomena indicate that the minerals have undergone high temperature oxidation.

5-2-5-6 Results of X-ray diffraction of bottom sediments

Four samples of bottom sediments studied microscopically were examined by X-ray diffraction. The results are shown in [Table 5-2-6](#) and the X-ray charts are laid out in [Attached Figure 5](#).

Calcite peaks were confirmed in all four samples, and a small amount of potash feldspar was recognized in BMS01A. Peaks of serpentine, chlorite, and iron oxide, which were found by microscopic studies, were not observed. Calcite peaks are believed to be that of coccolith which occupy more than 90% of all samples. The content of other minerals in the sample is very small compared to calcite, and thus x-ray diffraction peaks did not appear.

5-2-5-7 Gravity separation of bottom sediments

Gravity separation of the constituent minerals was attempted for sample BMS01B in which silt-size pyrite grains were observed. The pyrite had been mostly oxidized after recovery, and the color of the sample had changed from black at the time of sampling to brown. The separated sample was examined by x-ray diffraction and transmission electron microscopy (TEM, including EDS).

(1) Weight of gravity separated samples

The amount of separated samples is shown in [Table 5-2-7](#) in weight.

(2) Observation by stereoscopic microscope

The following minerals were observed under stereoscopic microscope. Microphotographs are shown in Attached Figure 4.

Heavy minerals: Clinopyroxenes>orthopyroxenes>amphiboles>magnetite>>pyrite

Light minerals: Calcite (coccolith)>>amphiboles>feldspar

Limonite observed in the smear slides was not found. Magnetite in the heavy minerals is believed to have separated during magnetic separation. Only one grain of pyrite was confirmed under the microscope. Some clinopyroxenes containing black inclusions were found. Almost all of the light minerals were coccolith.

(3) X-ray diffraction results

The detected minerals are as follows. X-ray charts are shown in [Attached Figure 5](#).

Heavy minerals: pyroxenes>amphiboles>>serpentine

Light minerals: calcite>>serpentine>amphiboles

(4) Results of transmission electron microscopy (TEM)

The results of transmission electron microscopy are reported below. Electron-microphotographs and EDS analysis results are shown in Attached Figure 4.

- **Pyrite grain**
A pyrite grain found under stereoscopic microscope was observed and analyzed by TEM. Many pyrite (FeS_2) particles, smaller than $8\mu\text{m}$ were confirmed, and the grain was clarified to be an aggregate of minute pyrite particles.
- **Pyroxene with black mineral inclusion**
The included black minerals were clarified to be magnetite, chromite, and other minerals. Pyrite was not included.

Sample before heavy liquid separation

Many doughnut-shaped parts of coccolith (CaCO_3) were confirmed. Bulk analysis showed the existence of Si, Al, Mg, and Fe together with Ca. Considering the results of stereoscopic microscope studies and x-ray diffraction, these elements are inferred to have derived from pyroxenes, amphiboles, and serpentine. Some peaks of S were, also, identified.

5-2-5-8 Microfossils in bottom sediments

Foraminifers and radiolarians in the sediments were identified in order to clarify the age and environment of sedimentation.

Microfossil identification was carried out on BMS01B, which was black at the time of recovery, and on pelitic limestone in CB01, which lies below BMS01. The fossils identified and their ages are listed in [Table5-2-8](#) and photographs of typical foraminifers are shown in Attached Figure 6. Age division of Berggren et al., (1995) were used. Radiolarian was not identified from these samples.

Colonies of planktonic foraminifers with age ranging from 120,000 to 220,000BP were confirmed in BMS01B, and those ranging from 120,000 to 650,000BP in BMS01C and CB01.

In the Pacific Ocean, the confirmed species were distributed mostly near 20 ~ 30°S. The benthic foraminifers indicating lower bathyal (800-1,000 to 2,000-2,500m depth) sedimentary environment were, also, identified from two samples of BMS01. The geologic age of these benthic fossils is not known.

5-2-5-9 Chemical analysis of manganese oxides

The analyzed sample consists of manganese oxide coating over altered dolerite collected at CB01.

The analyzed sample is shown in Attached Figure 4. A total of five elements, Co, Ni, Cu, Mn, and Fe were analyzed, and the limit of detection of each element was 0.01%. The analytical results are listed in [Table 5-2-9](#).

The total of the contents of Co, Ni, Cu, Mn, Fe, and Moisture (H_2O^+) is very low at 38.83%. This is due to the large content of other elements such as SiO_2 , TiO_2 , Al_2O_3 , MgO, CaO, K_2O , and P_2O_5 .

Fe-(Cu+Ni+Co)×10-Mn diagram is shown in [Figure 5-2-15](#). The boundaries in the diagram are those from Bonatti (1976) and Ishii (1988),

This diagram shows that this sample is poor in Cu, Ni, and Co, while rich in Fe and Mn. This is not within the area of hydrogenous iron-manganese oxides of the Pacific Ocean and the seas in the vicinity of Japan, but the samples are plotted near the area of hydrothermal manganese oxides.

5-2-5-10 Identification of shell fragments and ^{14}C age determination

(1) Identification of shell fragments

The shell fragments collected at CB01 and 02 were observed by unaided eyes and stereoscopic microscope, and classified into four species as listed in [Table 5-2-10](#).

The identification records of each species are shown in **Attached Table 7** together with photographs of representative samples.

Of the shells in the samples, large solemiid bivalves such as *Acharax* sp. are seen in the chemosynthetic molluscan communities in the Miocene Hayama Formation (Kanie and Kuromachi, 1995) and Pleistocene Koshiha Formation (Tate and Majima, 1998) in Japan. A solemiid bivalve which inhabits the vicinity of cold seeps is known to bear symbiotic chemoautotrophic bacteria in the soft body (Kulm et al., 1986). There is a high possibility that the present species is a member of the chemosynthetic community. The vesicomyiid bivalve *Calyptogena* sp. is an inhabitant near the hot and cold seeps, strongly suggesting the presence of such environments near the sampling site.

(2) Age determination by ^{14}C method

Fresh fragments of bivalves were selected from 99SFCB01HFR01 which were used for identification and they were used for the analysis.

The age of the shell was measured to be 3177 ± 60 (BP).

According to the study of vertical variation of ^{14}C ages of foraminifers in deep-sea sediments (Nozaki et al., 1977 and others) (Fig. 5), 3000 ~ 4000BP ^{14}C foraminifers occur in zones shallower than 7 ~ 8cm in depth, and mixing of the sediments by bioturbation occurs to a depth of 8cm from the surface. Considering the fact that the sample was collected from near the seafloor surface, the present value is considered to be reasonable.

5-2-5-11 Summary of laboratory tests

The rocks collected at Central Hill were determined by thin section microscopy as follows.

- (1) Ultra-mafic to mafic rocks such as peridotite (Iherzolite), gabbro, and dolerite.
- (2) Metamorphic rocks such as metagabbro, serpentine, metadolerite.

(3) Unmetamorphosed trachyandesite and basalt.

Gabbro and metagabbro are concluded by their chemical characteristics that they were derived from magma similar to island arc basalt, indicating the possibility of Central Hill once being an island arc. Gabbro is one of the major rocks constituting the basement of the Fiji Islands, and the results of the tests do not deny the theory that oceanic ridges and knolls on the northern side of NFB such as Central Hill separated from the Fiji Platform by the ERZ activity. Further, metamorphic mineral assemblages and cataclastic nature observed in some of the thin sections and occurrence of ultra-mafic rocks suggest that Central Hill had undergone episodes of tectonic movements.

The chemical composition of dolerite is similar to that of MORB type basalt collected at NS Valley, and the dolerite is possibly derived from magma with similar origin to that of ERZ.

Chlorite was identified in many samples indicating the possibility of hydrothermal alteration. Pyrite was found in sediments younger than 220,000BP. The pyrite particles are smaller than 8µm. High temperature oxidation is observed in the minerals of sediments.

The molluscs collected contain chemosynthetic molluscs. The age of 3177±60(BP) was obtained for these molluscs. The manganese oxides coating the rocks and shells were clarified to have composition similar to the hydrothermal iron manganese oxides.

5-2-6 Hydrothermal activity at Central Hill

At Central Hill, the following facts were confirmed indicating the possibility of hydrothermal activity around the protrusion near the mouth of the N-S trending creek at the summit.

1. Accumulation of shell fragments considered to be hydrothermal organism
2. Sediments containing pyrite
3. Discoloration of sediments
4. Coating of rocks by manganese oxides with composition close to hydrothermal iron-manganese oxides

Although confirmation of a chimney was not possible, a conical protrusion was observed in the central part of the discolored sediments.

Dolerite derived from magma different from the origin of the basement forming gabbroic rocks was sampled. This dolerite is believed to constitute a part of the protrusion indicating the possibility of a younger igneous activity after the formation of the basement.

The age of deposition of the sediments containing pyrite and the age of the shells differ, and thus the hydrothermal activity of this locality is considered to have occurred in cyclic manner.

The age of fossils in the sediments containing pyrite is 0.12~0.22Ma indicating the existence of volcanic or hydrothermal activity which supplied the pyrite during this period subsequently decreasing the pyrite supply.

The age of the shells is about 3,200BP and hydrothermal activity is believed to have been active during this time. During the present survey, organism communities were not confirmed and thus the hydrothermal activity is considered to have either ended or is about to end. However, water temperature anomalies have been detected at two localities near the center of discoloration indicating the possibility of the extrusion of hydrothermal solution.

Water temperature anomalies were detected also on the northern and eastern sides of the summit, but alteration accompanying discoloration of rocks and sediments were not confirmed.

Chapter 6 Conclusions and Evaluation

6-1 Conclusions

6-1-1 Survey results of Area 1

A topographic high of volcanic nature reaching to 1,900m in water depth occurs at the central part of the Triple Junction near 17°00' S and forms a dome-shaped topographic high of 500~600m in height from the neighboring seafloor. Graben structure is observed in the central part of this dome-topography towards the N15° direction, and localities of hydrothermal activities with chimney-mounds such as the White Lady site, Pere Lachaise site, SO99 site are discovered in this graben. Topographic survey of this Topographic High, and FDC and other surveys were carried out at SO99 site as preliminary to sampling by boring machine system (BMS).

A 2km wide central axis valley crosses the central part of this Topographic High in the NNE-SSW direction, and the body of the High consists of two parallel ridges and the graben of the central axis valley. Both slopes of the graben is steep and linear cliff of 40~60m in relative height, and the valley floor forms two to three step terraces.

The acoustic reflection intensity is high from the Triple Junction to the central axis valley in the NNE-SSW direction indicating thin unconsolidated sediment cover and exposure of relatively fresh rocks. The reflection intensity is also high on the ridges extending in the NNE-SSW direction, and the unconsolidated sediments are believed to be thin. Linear structures are observed at low localities between the ridges and the central axis valley, and sediments occur.

The SSS survey carried out in the above low part showed clear linear structures reflecting either fissures parallel to the valley axis or step structure. On the whole, sediments occur less in the western valley floor compared to the eastern terraces. Relatively fresh bedrocks are particularly exposed on the entire southern part and the north-central part of the valley floor.

Protruding topography indicating the possibility of chimneys and mounds are observed at places associated with linear structure interpreted to be step topography or fissures. These protrusions become notable to the north of 17°00'S and are distributed densely particularly to the north of 16°58'S.

In FDC images, occurrence of sheet lava was observed throughout the slope and the valley floor on

the western side. In the depressions on the southern and the central parts of the valley floor, lobate lava, collapsed lava lakes, and remnant pillars are seen. Pillow lava occurs locally along fissures and form rises of several meters on the seafloor. The seafloor is covered by thin pelitic unconsolidated sediments. Talus deposits occur in the lower parts of the valley slopes and steps and columnar-shaped boulders are seen in some localities.

Temperature anomalies were detected at 22 localities. Three sites with particularly high values are aligned in the N-S direction in the central part of the survey area. Chimneys, mounds, sulfur patches and discoloration of rocks and sediments were observed by FDC at 13 localities with temperature anomalies,

At SO99 site, mounds with confirmed chimneys were observed at 9 localities, and discolored parts considered to be mounds were found in several places around the high near 173°55.1'E and around depression at 173°55.3'E~55.4'E. The center of the present hydrothermal activity is at the central depression of the central axis valley, and the results of this survey indicate the possibility of further expansion of mineralized area.

Massive sulfide ore were collected by sampling at the depression of the northern part of the central axis valley. This massive sulfide is believed to be a constituent of a mound. It consists mainly of pyrite with some marcasite. The sulfur isotope analysis showed the $\delta^{34}\text{S}$ values close to that of pyrite from the hydrothermal system at mid-oceanic ridge.

6-1-2 Survey results of Area 2

Accurate seafloor topographic maps have not been prepared for the Fiji Fracture Zone. Therefore, the topographic survey was conducted and the following points were clarified by the present cruise.

Fiji Fracture Zone (FFZ) is an active structural zone extending from Triple Junction through Fiji Islands to Tonga Trench. It has a conspicuous E-W trending topography consisting of Yasawa and Yadua Troughs, oceanic ridges and other undulations. N-S trending valley topography such as Viwa Rift and ERZ A are, also, observed.

MBES results show that the acoustic reflection intensity is high at; shallow localities in the southwestern edge of the survey area, and ridge along FTF, and around ERZ A, indicating exposed rocks or thin sedimentary cover. Viwa Rift, where many N-S trending horst and graben structures occur, also have very high acoustic reflection intensity. The acoustic reflection intensity is relatively high at the eastern part of the Central Hill in the northeastern edge of the survey area and the trough in the south indicating thin sedimentary cover.

The total magnetic intensity of the survey area is within the range from 41,550 to 43,400nT and is generally high to the south and low to the north. This trend agrees with that of the international geomagnetic reference field (IGRF).

Reverse magnetic pattern is not seen from the magnetic anomaly map of this area, and most anomalies show positive magnetic pattern. The notable positive magnetic anomaly zones are:

- (1) Ridge with SW-NE trending axis in the western edge
- (2) Northern Edge of the Viwa Rift
- (3) The flat zone between the Central Hill and N-S Ridge

The existence of ferromagnetic rock bodies are inferred below the seafloor of the areas (2) and (3).

The distribution of the reduction to the pole anomalies in this area has the following tendency.

- The contrast of magnetic anomalies increases.
- The correlation between the anomalies of reduction to the pole and the seafloor topography is not clear for the whole area.
- The values of the anomalies of reduction to the pole range from -779nT to 1112nT, and the variation of the values is large.
- As the positive magnetic anomaly migrates southward, the area of positive magnetic anomaly distribution increases and that of the negative anomaly decreases. The value of the positive magnetic anomaly, also, increases.

The distribution of the magnetization intensity has the following general tendency.

- The magnetization intensity of this area is relatively strong ranging from -3.1A/m to 3.1A/m.

- The intensity and the variation of intensity of magnetization tends to be stronger in the western part, and decreases to the east.
- From the eastern part to the western edge of the Yasawa Trough, the intensity of magnetization does not agree with the large-scale topographic direction of the seafloor, but coincides with the small-scale directionality of the oceanic ridges and seamounts. Throughout the area, the large-scale positive magnetization anomalies are located at the western edges of large troughs.
- From the western end of the central part to the western part, the zone of positive magnetization agrees with the seafloor topography, indicating different magnetic structure from the eastern part.

The characteristics of the magnetic structure of the Fiji Fracture Zone are as follows.

- Banded structure is not observed in this area at present.
- Magnetic anomalies suggesting reverse magnetization have not been detected.
- In the eastern part, ferromagnetic rock bodies are dominantly aligned in the N-S direction, but E-W to NE-SW alignment is dominant in the central to the western part.

The relation of ferromagnetic rock bodies and topographic highs is completely different between the western and eastern part. In the western part, ferromagnetic bodies are distributed at the topographic highs such as spreading axis and ridges, while in the eastern part, the correlation of ferromagnetic bodies and topographic highs is small with the exception of such bodies at small highs such as Central Hill, N-S Ridge, and Viwa Rift.

6-1-3 Survey results of ERZ A

ERZ A was considered to be a promising area regarding the occurrence of hydrothermal activity from the survey results of Area 2. Thus SSS, FDC, CB sampling, and drilling was carried out in this area.

1. The seafloor to the north of Fiji Platform between Yasawa Trough and Yadua Trough forms a gentle rise. A valley (N-S Valley) trending in the N-S direction occurs in the central part of this rise

and three to four plains of terraces occur on both sides of the valley. ERZ A spreads in the E-W direction and it has graben which is considered to have formed by N-S system of normal faults associated with this spreading.

2. The MBES acoustic reflection intensity is high at the N-S Valley in the central part indicating distribution of less sediments in the N-S trending depressions compared to the vicinity.
3. By SSS survey, it was shown that generally the rocks were either exposed or covered by thin sediments in the valley, and that linear structures were very few at the northern part of the valley floor thus suggesting the existence of lava flow. The southern part of the valley floor has slightly lower reflection intensity and the existence of sediments is inferred. Here linear structure believed to be fractures along the topographic alignment is clearly seen, particularly in the southern part of the valley floor and the terraces on the western side. Topographic features of knolls or small mounds are observed near the northern end of the track line, near 16°24'S at the valley floor, and near 16°26'S on the summit of the N-S Ridge.
4. Cracks and small cliffs are hardly seen in the deepest depression, sheet lava is widely distributed, and thus it is believed that young magmatic activities involving the extrusion of large amount of lava occurred. Pillow lava occurs sporadically covering this sheet lava. N-S trending faults are believed to be developed near the boundary of the eastern margin of the deepest depression and the lower slope, and pillow lava activity is considered to have occurred along these faults. The lower slope below the middle terrace and upper slope above the middle terrace of the slope between the N-S Valley and N-S Ridge are covered by sheet lava and massive lava. Pillow lava occurs continuously on the summit of the N-S Ridge. The upper slope is believed to be fault scarp because N-S trending cracks are found near the boundary between the middle terrace and the upper slope, and the upper slope is steep with linear N-S trend.
5. The dark brown to reddish brown discolored zone of rocks pebbles and sediments occur as spots of tens of centimeters on the upper part of the lower slope of and the base of the upper slope of the N-S Ridge.
6. The water temperature anomalies were obtained at the locations where discolored zones of rocks and pebbles were observed. Other than these, the anomalies were found at the locations where pillow lava occurs.
7. Regarding sampling, basalt was collected by dredging at one site at the N-S Valley floor, and by drilling at two localities on the base of the western upper slope of the N-S Ridge. Minute pyrite grains were found in the druses of the basalt from the valley floor. Chemical analysis showed that samples from the above three localities have composition similar to mid-oceanic ridge basalt (MORB).

6-1-4 Central Hill

The results of the Area 2 survey indicates that this area is located at the northern extension of ERZ A, and has fissures extending in the same direction as the ERZ A structure. The Hill is considered to have possibility of hydrothermal activity and FDC, drilling, dredging, and LC surveys were carried out.

1. The Central Hill, located in the northern extension of ERZ A, has almost regular triangle shape. There is a gentle knoll-shaped rise on the summit, and N-S trending creek topography is found on the northeastern slope near the summit. FDC, drilling, dredging, and LC were carried out around this N-S trending valley topography.
2. FDC observation showed that the summit is generally smooth with some protrusions of several tens of meters in relative height and steep cliffs of several meter displacement. Most of the steep cliffs toward the northern to northeastern slope and trend in the N-S direction, but fractures at the upper reaches of the creek trend in the E-W direction across the creek. The rocks mostly have the appearance similar to sheet lava with pelitic unconsolidated sediment cover. Rocks which appear to be pillow lava are found in small amount near the fissures and small ridge-like protrusions. Pelitic unconsolidated sediments occur throughout the survey area and are relatively thin.
3. Accumulation of white bivalve shell fragments was confirmed by FDC observation. The shell fragments are distributed over a length of more than 700m of each track line, and particularly at the mouth of the creek they are observed continuously for about 300m in both E-W and N-S directions. Here discoloration is observed on parts of the rocks and sediments. A conical protrusion considered to be chimney was seen in the central part of the discolored zone.
4. Water temperature anomalies were extracted at; sites of chimney-shaped protrusion, creek on the eastern side of the summit, and the northern side of the summit. East-west trending small cliffs and cracks are developed at the temperature anomaly by the creek. N-S trending small cliffs are seen at the anomaly on the northern side of the summit, and deposition of pebbles with appearance of pillow lava were found.

Sampling was carried out as follows. CB sampling at two sites, LC at one site, and drilling at two sites around the shell fragment accumulation. The collected samples consisted of gabbro, serpentinite, dolerite, basalt, trachyandesite, and limestone. The surface of rocks and shell fragments is coated by manganese oxides. In addition, sediments containing minute pyrite grains were collected by seafloor drilling.

The chemistry of the collected gabbro indicates the origin of magma similar to that of island arc basalt. It shows the possibility that Central Hill was once a part of an island arc. On the other hand, dolerite differs in composition to gabbro and is similar to that of MORB. Thus it is inferred that there

were two igneous activities at different periods in this area.

The shells were identified to be included in chemosynthetic molluscan communities which inhabit near hot and cold seeps. The age of these shells were determined to be 3,200BP. The nature of manganese oxides which coat the surface of rocks and shell fragments were identified to have composition similar to hydrothermal iron manganese oxides.

6-2 Evaluation

6-2-1 Area 1

This survey is based on the results of the So-99 and So-134 cruises of R/V Sonne. This survey clarified that, in the SO99 site, the present center of hydrothermal activity is probably in the central depression of the central axis valley, and that the distribution of the mineralized zones is possibly wider than what was formerly known. Pere Lachaise site located west to southeast of the SO99 site consists of dormant chimneys and major mounds are not found (Bendel et al., 1993), on the other hand, large mounds and water temperature anomalies are observed at SO99 site indicating the possibility of continuing hydrothermal activity. Furthermore, it would be desirable to accurately clarify the distribution of the mounds by FDC observation and the nature of mineralization by detailed sampling and analysis, in the future.

The SO99 site has an areal extension of about 1km x 1km and its hydrothermal activity is inferred to be as good as that in Manus Basin. But the amount of samples collected is small, and accurate chemical nature could not be determined.

6-2-2 ERZ A

It was pointed out by the Sonne 35 cruise that the ocean floor is spreading in the E-W direction from N-S Valley, and that there is a possibility of hydrothermal activity because a basalt sample containing pyrite was collected (Stackelberg et al., 1990; Johnson and Sinton, 1990). Now, the detailed seafloor topography near the N-S Valley is clarified by the present survey. It indicates that the present ERZ A area was formed by spreading in the E-W direction from the deepest depression of the N-S Valley and repeated formation of graben by N-S normal system faulting associated with the spreading. The beginning of spreading is inferred, from the rate of FFZ lateral movement, to be 0.26Ma (Hughes-Clarke, 1993) and 0.51Ma (Johnson and Sinton, 1990). The results of the present survey also indicate that the spreading occurred after the Brunhes chron (0.73Ma).

The results of FDC observation and the distribution of the water temperature anomalies indicate that the present hydrothermal activities occur at localities where fractures and small cliff with N-S trend occur near the boundary of terrace and slope. The boundaries between the terraces and the slopes are believed to be faults which act as conduits for the hydrothermal fluids. On the other hand, the deepest depression is covered by sheet lava caused by the effusion of a large amount of magma and the possibility of hydrothermal activity is small.

Although the possibility of present hydrothermal activity near the N-S trending steep cliffs between terraces is high, the results of the present survey only suggest the possibility and further detailed survey including the deepest depression is desirable for ascertaining the existence of such hydrothermal activity in the area.

6-2-3 Central Hill

At Central Hill, Sonne 35 cruise carried out dredging at one site, and no other surveys have been carried out in this area. By the present survey, rock samples considered to constitute the basement were collected, and the possibility of ongoing hydrothermal activity became clear.

The samples collected by CB, LC, and drilling are gabbroic rocks, ultramafic rocks, dolerite, and others. Most of the gabbro have been metamorphosed or mylonitized, and considering the fact together with the occurrences of serpentinized ultramafic, a strong tectonic movement is believed to have taken place in the area at one time. Further, the gabbroic rocks show composition close to island arc tholeiite, indicating that Central Hill originally was a part of an island arc. The ridges located to the north of the Fiji Platform, such as Braimer Ridge, Central Ridge, and Yadua Ridge including Central Hill, are believed to have been parts of the Fiji Platform and they were separated from it by the pull apart structure of FFZ (Rao et al., 1990; Jarvis et al., 1994). The rock samples collected in the Central Hill during the present survey support this theory.

Dolerite, on the other hand, has a composition close to that of MORB. The Central Hill is located in north extension of N-S Valley (ERZ A), and dolerite is believed to have been the product of magmatic activity associated with spreading of ERZ A after the separations of the Central Hill from the Fiji Platform. The hydrothermal activities are inferred to be related to this igneous activity.

Accumulations of shell fragments which are hydrothermal organisms and sediment containing pyrite have been found, indicating the occurrence of hydrothermal activity, and also chimney-shaped protrusions were observed.

Measurement of ^{14}C of the shell fragments indicate that hydrothermal organism communities were formed about 3,200BP. The foraminifers in calcareous clay containing pyrite show their ages to be 120,000 to 220,000 BP and is different from the ages of the shells. If these ages were that of hydrothermal activities, it is possible that the hydrothermal activities occurred in cycles of active and dormant periods.

Presently living organisms were not found in this survey. The hydrothermal activity which formed these communities is probably dormant or is about to terminate at present. However, water temperature anomalies were detected at two localities near the center of the discolored parts and welling out of hydrothermal fluids could be still continuing.

Although hydrothermal activities were not found by the present survey at Central Hill, but conspicuously large accumulation of shell fragments was located near the rise on the summit over an area of 300 square meters. The possibility of a mound existing beneath the unconsolidated sediments is large, and drilling in the future to determine the details is desired.

References

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

Auzende, J. M., Eissen, J.P., Caprais, M. P., Gente, P., Gueneley, S., Harmegnites, F., Lagabrielle, Y.,

Lapouille, A., Lefevre, C., Maillet, P., Maze, P.P., Ondreas, H., Schaaf, A., and Singh, R.(1986): Accretion oceanique et deformation dans la partie meridionale du bassin Nord-Fidjien, Resultats preliminaires de la campagne oceanographique SEAPSO 3 du N.O.Jean Charcot (Decembre 1985): Academie des Sciences (Paris)Comptes Rendus, V.303, ser.2, 93-98.

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

Auzende, J. M., Lafoy, Y., and Marsset, B. (1988b): Recent geodynamic evolution of the North Fiji Basin (SW Pacific), *Geology* 16, 925-929.

Auzende, J. M., Honza, E., and the STARMER Group (1990): Bathymetric map of the North Fiji Basin Ridge between 16°10'S and 21°40'S, published by IFREMER and STA Japan, six colored sheets edited by Beicip, Paris.

Auzende, J. M., and the STARMAR Group (1990b): Active spreading and hydrothermalism in the North Fiji Basin (SW Pacific). Results of Japanese-French cruise Kaiyo 87, *Mar. Geophys Res.*, 12, 269-283.

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

Auzende, J. M., Pelletier ., Eissen J. P. (1995): The North Fiji Basin. Geology, structure and geodynamic evolution. In B. Taylor ed. *Backarc Basin: Tectonics and Magmatism*, Plenum Press, New York, 1995, 139-175

Brocher, T.M. (ed.)(1985). Geological investigation of the Northern Melanesian borderland: CircumPacific Council for Energy and Resources. *Earth Sci. Ser., Am. Assoc. Pet. Geol.*, 3, 199 pp.

Carney,J.N. and MacFarlane, A.(1982): Geological evidence bearing on the Miocene to recent structural evolution of the New Hebrides arc. *Tectonophysics*, 88, 147-175

Carney, J. M., Macfarlane, A. and Mallick, D. I. J. (1985): The Vanuatu island arc: An outline of the stratigraphy, structure, and petrology. In A. E. M. Nairn et al. (ed.) *The ocean basin and Margins*, Vol. 7A, *The Pacific Ocean*, New York, pp.683-718.

- Chase, C. G. (1971): Tectonic history of the Fiji Plateau. *Geol. Soc. Am. Bull.*, 82, 3087-3110.
- Coleman, P.J. and Packham, G. H. (1976): The Melanesian Borderlands and India-Pacific plates' boundary. *Earth Sci. Rev.*, 12, 197-233
- Doutch, F. (ed.) (1981): Plate tectonic map of the Circum-Pacific region, southwest quadrant. *Amer. Assoc. Petrol/Geol.*
- Falvey, D. A. (1975): Arc reversals, and a tectonic model for the North Fiji Basin, *Austr. Soc. Explor. Geophys. Bull.* 6, 47-49.
- Falvey, D. A. (1978): Analysis of paleomagnetic data from New Hebrides, *Austr. Soc. Explor. Geophys. Bull.*, 9, 117-123.
- FU Berlin and Partner (1998): Hydrothermal fluid development, material balancing and special biological activity in the North Fiji Basin. Technical Cruise Report , Hyflux II -SO134-, p148
- Halunen, A. Jr. (1979): Tectonic history of the Fiji Plateau, Ph.D. thesis, University of Hawaii, Honolulu.
- Honza, E., (1991): The Tertiary arc chain in the Western Pacific. *Tectonophysics*, 187, 285-303.
- Huchon, P., Gracia, E., Ruellan, E., Joshima, M., and Auzende J., M. (1994): Kinematics of active spreading in the central North Fiji Basin (Southwest Pacific). *Marine Geology*, 116, 69-87.
- Ishibashi, J., and Urabe T. (1995): Hydrothermal activity related to arc-backarc magmatism in the western Pacific, In B. Taylor ed. *Backarc Basin: Tectonics and Magmatism*, Plenum Press, New York, 1995, 451-495.
- Luyendyke, B. P., Bryan, W. B., and Jezek, P. A. (1974): Shallow structure of the New Hebrides island arc. *Geol. Soc. Am Bull.*, 85, 1287-1300.

- Malahoff, A., Feden, R. H. and Fleming, H. F. (1982a): Magnetic anomalies and tectonic fabric of marginal basins north of New Zealand, *J. Geophys. Res.*, 87, 4109-4125.
- Malahoff, A., Hammond, S. R., Naughton, J. J., Keeling, D. L., and Richmond, R. N.(1982b): Geophysical evidence for post-Miocene rotation of the island of Viti Levu, Fiji and its relationship to the tectonic development of the North Fiji Basin. *Earth Planet. Sci. Lett.*, 57, 398-414.
- Monzier, M.,Maillet, P., and Dupont, J. (1991): Carte bathymetrique des parties meridionales de l' arc insulaire des Nouvelles-Hebrides et du bassin Nord-Fidjien, Institut Francais de Recherche Scientifique pour le Developpement en Cooperation, Editions de l'ORSTOM, Paris.
- Packham, G. H. (1982):Foreword to paper on the tectonics of the south west Pacific region. *Tectonophysics*, 87, 1-10
- Ruelle, E., Huchon, P., Auzende, J. M., and Gracia, E. (1994): Propagating rift and over lapping spreading center in the North Fiji Basin, *Mar.,Geol.*, 116, 37-56.
- Stackelberg, U. von and Rad, U. von (1990): Geological evolution and hydrothermal activity in the Lau and North Fiji basin (Sonne Cruise SO-35)-a synthesis, *geol, Jb.*, 92, 629-660.
- Urabe, T., Auzende, J. M., et al. (1992): Bathymetric map of the central part of the North Fiji Basin, southwest Pacific, between 12°20'S and 21°50'S, 2 colored maps, scale: 1/500,000, Published under the Special Coordination for Promoting Science and Technology (Japan).

Appendix

[Attached Figure1 \(1\) MBES Track Line Map \(West Area\)](#)

[Attached Figure1 \(2\) MBES Track Line Map \(East Area\)](#)

[Attached Figure1 \(3\) MBES Track Line Map \(Triple Junction Area\)](#)

[Attached Figure1 \(4\) MBES Track Line Map \(ERZ A Area\)](#)

[Attached Figure 2 Water Temperature Profile along FDC Lines \(1\), \(2\), \(3\), \(4\), \(5\)](#)

[Attached Figure 3 Description of LC Cores](#)

[Attached Figure 4 Sample Photographs](#)

[Attached Figure 5 Chart of X-ray Diffraction Analysis](#)

[Attached Figure 6 Photographs of Foraminifers](#)

[Attached Figure 7 Photographs of Shell](#)

[Attached Figure 8 Microscopic Photographs of Ore Sample](#)

[Attached Figure 9 CTD Observation Result](#)

[Attached Table 1 Mineral Showing Observed by FDC in Area 1](#)

[Attached Table 2 List of Samples](#)

[Attached Table 3 Description of Microscopic Observation for Rock Thin Sections](#)

[Attached Table 4 Results of Smear Slide Observation](#)

[Attached Table 5 List of Sound-Velocity to Water Depth for MBES](#)

[Attached Table 6 Condition of Water and Sea](#)