Appendix 5

Laboratory Works 5－2

1．Microscopic observation of Igneous rocks
2．Whole rock chemistry of Igneous rocks
3．K-Ar Dating of Igneous rocks

5-2 1. Microscopic Observation of Igneous Rock

1-1 Samples

Typical samples of the volcanic rocks collected in the ERZ A by dredge were examined by microscope (Table 1). The microscopic observation was conducted by Dr. Eij Hirano, Geological Laboratory of HIRANO.

Table 1 Sample List of Microscopic Observation

Area	Sampling No.	Depth (m)	No. of Individual Sample	Lithology	Sample No.
ERZ A	04SFAD02	1956-1803	C3	vitric surface of basalt	04SFAD02 TS01
			C5	fragments of quenched	04SFAD02 TS02
	04SFAD03	1954-1801	C5	small pillow or tube	04SFAD03 TS01
			C6	crust of lava flow surface	04SFAD03 TS02
	04SFAD04	1941-1925	C1	fragments of autobrecciated lava	04SFAD04 TS01
			C3	part of pillow lava	04SFAD04 TS02
	04SFAD05	2072-1955	C2	fragments of autobrecciated lava	04SFAD05 TS01
			C5	part of pillow lava	04SFAD05 TS02

1-2 Results of Microscopic Observations

The results of microscopic observation are given in Table 2, and descriptions of each hand specimen and thin sections are given at the end of chapter.

1-3 Considerations

The samples of 04SFAD02 and 04SFAD03 are clinopyroxene basalt, and samples of 04SFAD04 and 04SFAD05 are, respectively, olivine basalt and aphyric basalt All of the samples are vitric and abundance of phenocryst is less than 10%. Vesicles are commonly observed, occupying 10 to 30vol%. All the samples are relatively fresh and even slightly altered samples (04SFAD03TS02 and 04SFAD04TS02) only show a small amount of clay in vesicles and along cracks.

The samples of 04SFAD02 and 04SFAD03 have phenocrysts of plagioclase and clinopyroxene, and the groundmass consists of plagioclase and clinopyroxene, in addition to olive only in 04SFAD03 samples. Opaque minerals (magnetite) are observed only in 04SFAD03TS02. The groundmass olivine does not show reaction rim. Aggregations of acicular (microlite) clinopyroxene and plagioclase of orbicular shape commonly occur. The samples of 04SFAD03 characteristically show amygdaloidal opaque glass (appearance of microlith).

The samples of 04SFAD04 have plagioclase and olivine phenocrysts with groundmass of plagioclase, olivine and clinopyroxene. Opaque minerals (magnetite) are observed in groundmass of 04SFAD04TS02. The olivine in 04SFAD04 TS01 is acicular crystal, while that of 04SFAD04 TS02 is subhedral to euhedral crystal. Reaction rim is not observed in these samples.

Although 04SFAD05 samples are aphyric, plagioclase phenocrysts are rarely observed. The groundmass, showing texture similar to samples of 04SFAD04, consists of plagioclase, clinopyroxene and magnetite.

Orthpyroxene and silica minerals were not found in any samples and olivine does not show reaction rim. The microscopic observations suggest all samples are silica under-saturated ocean floor basalt.

Table 2 Results of Microscopic Observation

Area	Lithology	Sample No.	Rock Name	Texture	Alteration	Amount of Phenocryst	Phenocryst			Groundmass						Secondary			Remarks
							Pl	Ol	Cpx	Pl	Ol	Cpx	Oq	Ap	G	Smc	Si	Goe	
ERZ A	vitric surface of basalt	04SFAD02 TS01	Cpx basalt	Cryptocrystalline-hyaloophitic	not observed	△	△	-	+	-	-	○	-	-	◎	-	-	-	
	fragments of quenched basalt	04SFAD02 TS02	Cpx basalt	Porphyritic, cryptocrystalline	not observed	△	△	-	+	○	-	◎	-	-	◎	-	-	-	
	small pillow or tube	04SFAD03 TS01	Cpx basalt	Cryptocrystalline-hyaloophitic	not observed	△	+	-	+	○	+	○	-	-	◎	-	-	-	
	crust of lava flow surface	04SFAD03 TS02	Cpx basalt	Porphyritic, cryptocrystalline	weak	△	△	-	+	△	△	○	+	-	◎	△	-	-	
	fragments of autobrecciated lava	04SFAD04 TS01	Ol basalt	Hyaloophitic-intersertal	not observed	+	+	+	-	○	△	◎	-	-	◎	-	-	-	Foraminifera, calcite in cavity
	part of pillow lava	04SFAD04 TS02	Ol basalt	Intersertal	weak	△	△	+	-	○	+	◎	△	-	◎	△	-	△	
	fragments of autobrecciated lava	04SFAD05 TS01	Aphyric basalt	Hyaloophitic	not observed	+	+	-	-	○	-	○	+	-	◎	-	-	-	
	part of pillow lava	04SFAD05TS02	Aphyric basalt	Hyaloophitic	not observed	+	+	-	-	△	-	○	+	-	◎	-	-	-	

Amounts (%):
◎ Dominant (>30)
○ Major (10-30)
△ Minor (3-10)
+ Trace (<3)

Mineral name:
Pl: Plagioclase
Ol: Olivine
Cpx: Clinopyroxene
Oq: Opaque mineral

No1

Sample Number:01_04SFAD02-TS01

Rock type:Clinopyroxene basalt

Naked eye observation: Glassy surface of dark-colored basalt lava. Magnetism is rarely recognized in the inner part, but is not recognize at the surface.

Microscopic observation

Texture: Cryptocrystalline-hyaloophitic texture. Transparent glass layer is also recognized. Small amount of plagioclase phenocryst is observed.

Phenocryst

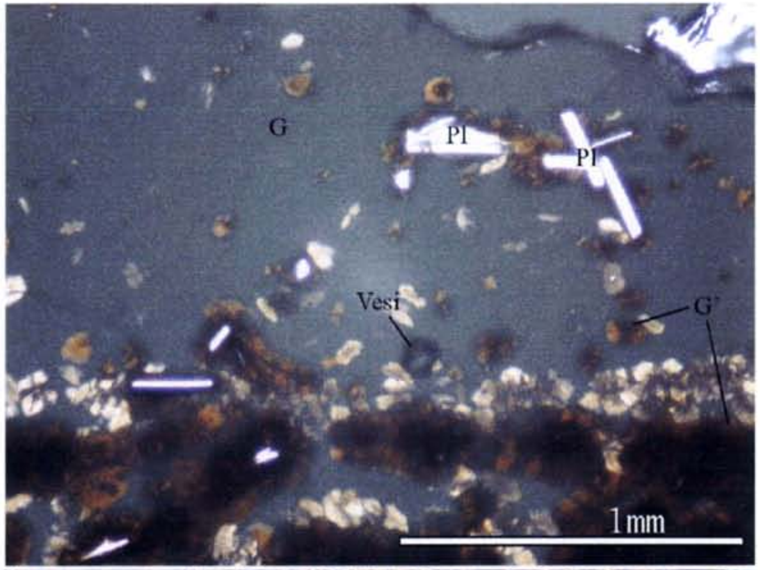
Mineral	Texture	Size(mm)	Volume (%)	Description
Plagioclase	prismatic	0.5-3.0	5	Many hollows occupied by glass.
Clinopyroxene	short-prismatic	0.6-1.0	< 1	Glomeroporphyritic with plagioclase.

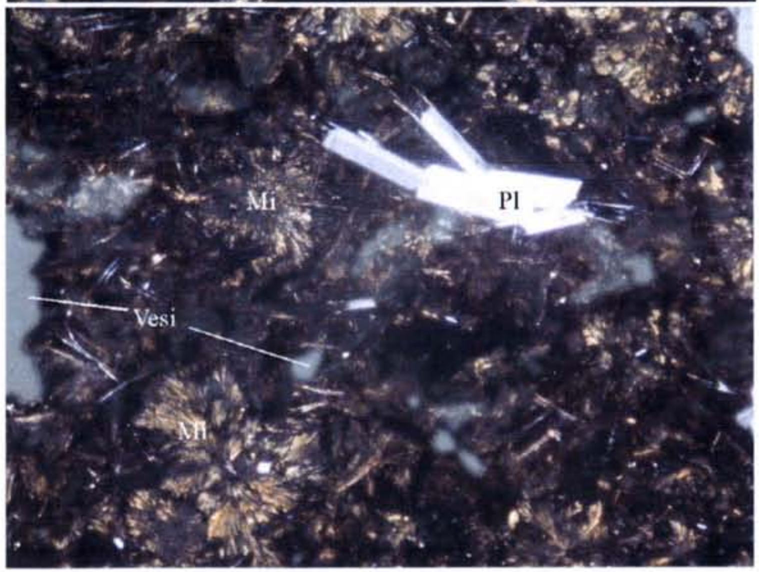
Groundmass: Composed of almost turbid glass and clinopyroxene microlite. Vesicle (0.05-0.08mm diameter) is slightly observed.

Mineral	Texture	Size (mm)	Volume (%)	Description
Clinopyroxene?	fibrous	0.2-0.1 (length)	30	Crystallized as crystallite-microlite in glass. Micro vesicles are observed around the crystal.
Turbid glass	dark brown		50	Often associating with microcrystal (e.g. plagioclase)
Clear glass	pale brown		20	

Alteration: Not altered

Mineral	Texture	Size (mm)	Volume (%)	Description





No.2

Sample Number: 02_04SFAD02-TS02

Rock type: Clinopyroxene basalt

Naked eye observation: Dark-grey, glassy, fine grained and vesicler volcanic rock. Pyroxene and plagioclase phenocryst are scarcely observed. Magnetism is low in fine grained part and quite low in smooth glass part.

Microscopic observation

Texture: Porphyritic texture. Turbid glassy – hyaloophitic groundmass. Clear layer with Valiole (clinopyroxene microlite) and turbid-dark gray glassy layer makes banded texture. Plagioclase phenocryst is rarely observed.

Phenocryst

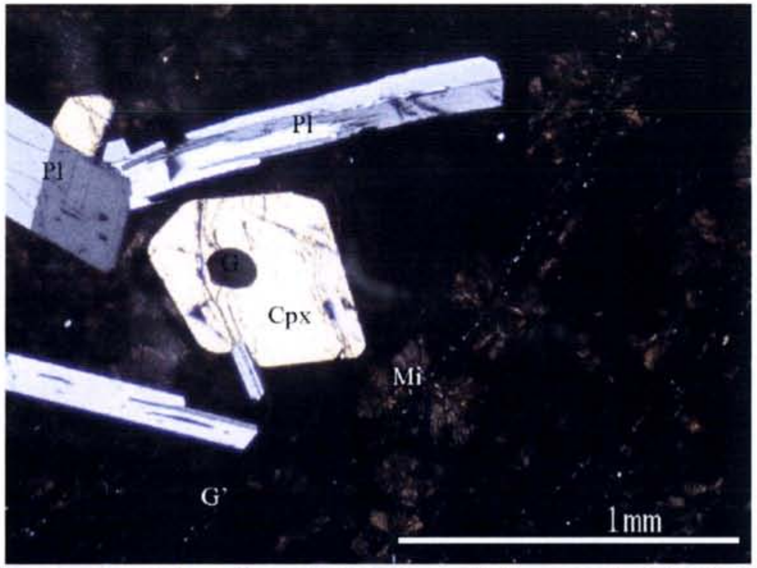
Mineral	Texture	Size(mm)	Volume (%)	Description
Clinopyroxene	subhedral, prismatic	0.5-1.0	~1	Subophitically including plagioclase. Hollows occupied by glass.
Plagioclase	prismatic	0.3-1.5	5-10	Glomeroporphyritic.

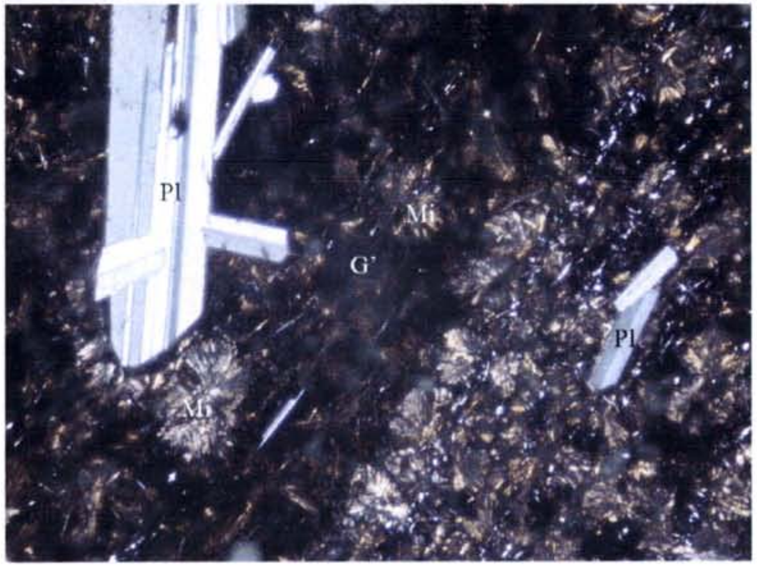
Groundmass:

Mineral	Texture	Size (mm)	Volume (%)	Description
Clinopyroxene microlite	Feather	0.1(length)	40	Radiated-bow-like shape. Turbid. Pale-brown.
Plagioclase	Acicular	0.1(length)	10	Clear and straight shape microlite.
Magnetite	Anchor-like	fine grain	<1	Associating with clinopyroxene.
Glass	Clear–turbid	-	40-50	
Vesicle	Rounded	0.001-0.4	1-5	Associating with turbid glass or microlite.

Alteration: Not altered

Mineral	Texture	Size (mm)	Volume (%)	Description





No.3

Sample Number:03_04SFAD03-TS01

Rock type:Clinopyroxene basalt

Naked eye observation: Marginal part of pillow or tube. Minor feldspar phenocryst bearing dark-gray fine grained rock with glassy crust (volcanic rock?). Vesicles are abundant in the groundmass. Magnetism is weak at fine grained part and quite weak in clear glass layer.

Microscopic observation

Texture: Cryptocrystalline to hyaloophitic texture. Few pyroxene phenocrysts are observed. Groundmass is composed from glass, acicular feldspar and clinopyroxene microlite. Vesicle are round ~irregular shape and occupies about 5 vol% of groundmass

Phenocryst

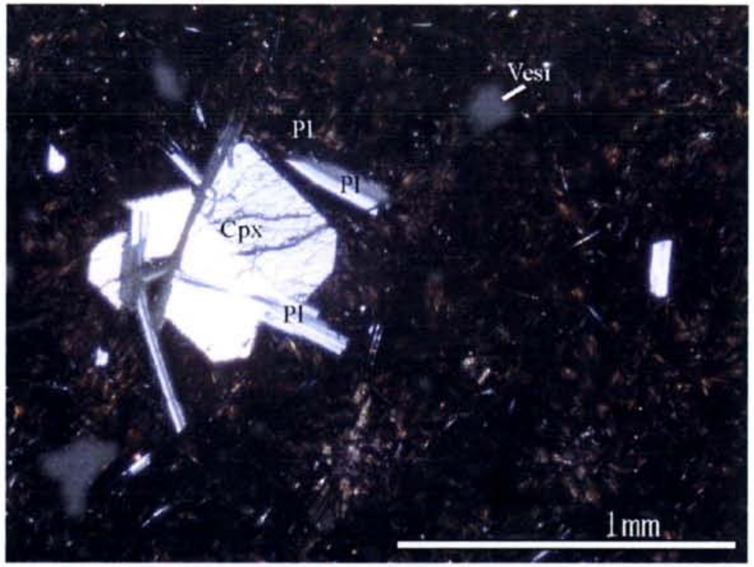
Mineral	Texture	Size(mm)	Volume (%)	Description
Clinopyroxene	subhedral, prismatic	0.5-1.5	2	Including prismatic feldspar.
Plagioclase	prismatic	0.2-1.2	2	Partly glomerporphyritic. Irregular edge and hollow are observed.

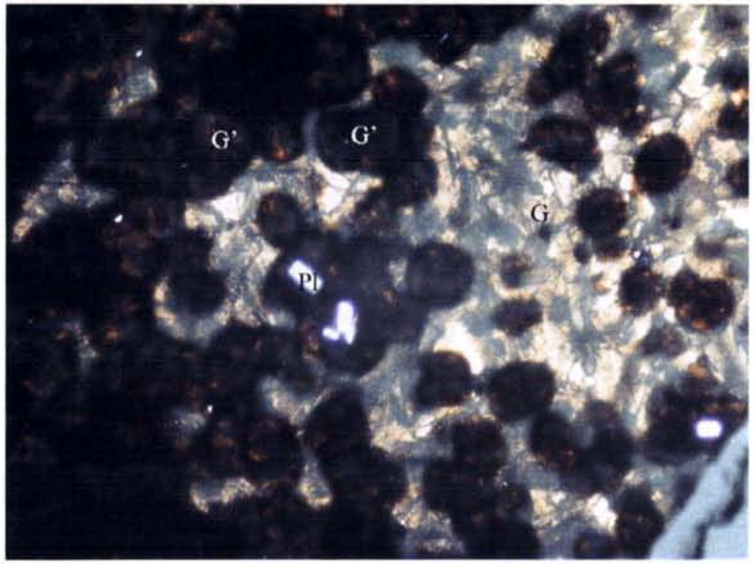
Groundmass: Cryptocrystalline to microlite with minor glassy layer. Acicular plagioclase and round to irregular vesicles are also observed. Vesicles are abundant in microlite rich part.

Mineral	Texture	Size (mm)	Volume (%)	Description
Plagioclase	Acicular~ prismatic	~0. 2 (length)	~10	
Clinopyroxene	Microlite	~0. 2 (length)	30	Feathered, high optical dispersion
Olivine	Granular	0.01	~1	High double refractive index, square or acicular microlite
Glass	Brown, turbid	0.05-1.5	~50	
Vesicle	Rounded, irregular		~5	

Alteration: Not altered

Mineral	Texture	Size (mm)	Volume (%)	Description





No.4

Sample Number: 04_04SFAD03-TS02

Rock type: clinopyroxene basalt

Naked eye observation: Crust of the lava surface. Dark gray glassy fine grain volcanic rock (?). Plagioclase phenocryst is observed. Magnetism is weak at fine grained part and quite weak at the glassy part. Partly vesicular.

Microscopic observation

Texture: Porphyritic texture and cryptocrystalline in groundmass. Transformation from clear glass to turbid glass by the virile crystallization is observed. Smectite partly occupies round vesicle.

Phenocryst

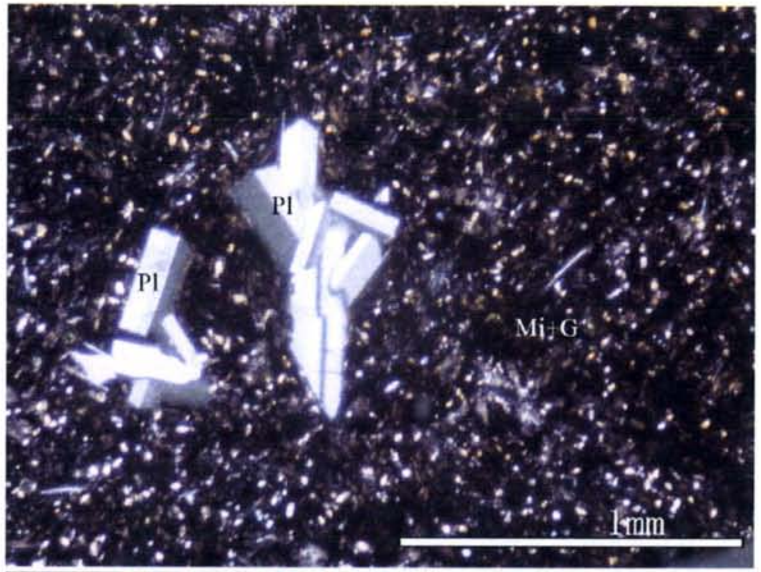
Mineral	Texture	Size(mm)	Volume (%)	Description
Plagioclase	Prismatic, tabular	0.1-2.0	5	Subophitically enclosed by pyroxene in part. Small crystal tends to be thin.
Clinopyroxene	Short prismatic	0.2-0.4	<1	Enclosing prismatic plagioclase

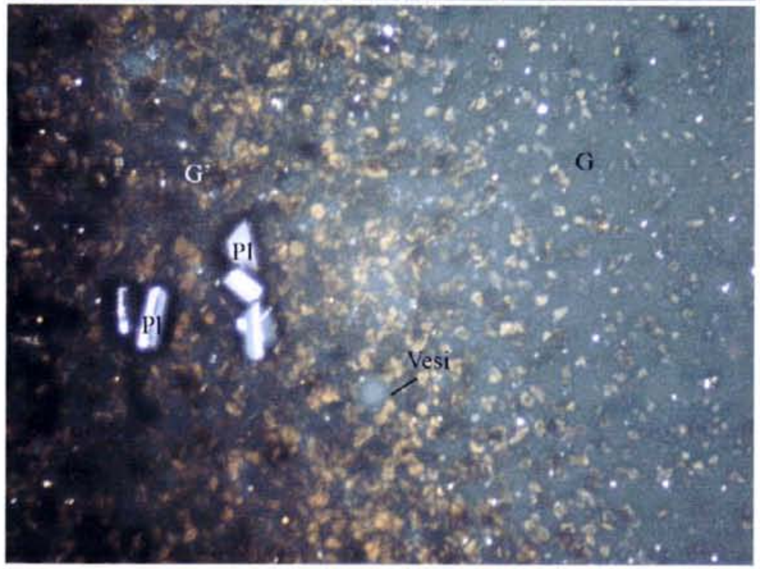
Groundmass: Except for the glassy part, microcrystalline-cryptcristalline. Granular olivine, fan-like clinopyroxene and acicular plagioclase are observed.

Mineral	Texture	Size (mm)	Volume (%)	Description
Clinopyroxene	Fan-like	0.1-0.2	~20	Microlith, pale gray. Turbid.
Plagioclase	Acicular	0.1(Length)	~10	Clear.
Olivine	Granular	0.001	~5	Clear. High- birefringence.
Magnetite	Granular	Micro	~1	
Glass	-	-	~50	Clear or turbid.
Vesicular	Oval	0.03-0.2	~5	

Alteration: Altered along the fracture. Clay minerals occupy the vesicles.

Mineral	Texture	Size (mm)	Volume (%)	Description
Smectite	Occupying the vesicle		~3	Flake-film. Deep yellow - orange.





No.5

Sample Number:05_04SFAD04-TS01
Rock type:Olivine basalt

Naked eye observation: Dark gray and fine grained volcanic rock? Aphyric and vesicular. Magnetism is rather high.

Microscopic observation

Texture: Hyallophytic~intersertal texture. Little amount of olivine and plagioclase phenocrysts are observed.

Phenocryst

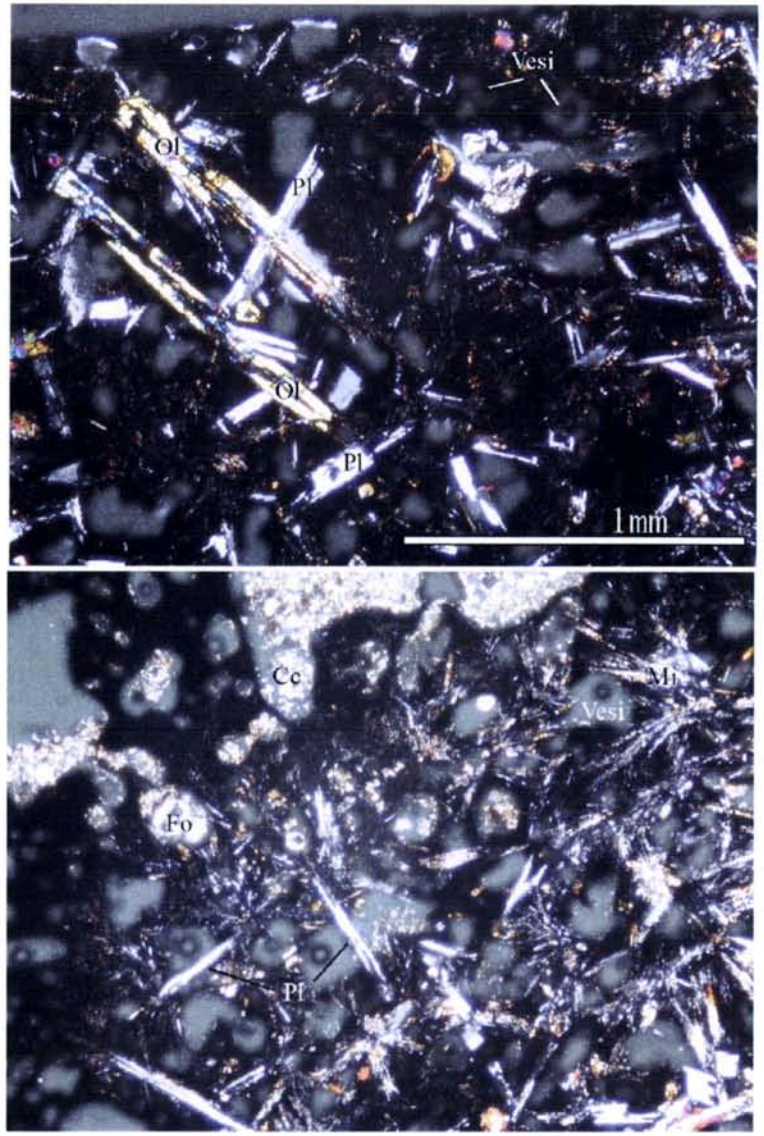
Mineral	Texture	Size(mm)	Volume (%)	Description
Olivine	Prismatic	0.2-0.3	~1	Microphenocryst. Small phenocryst is similar size to groundmass crystal.
Plagioclase	Tabular	0.2-0.3	~1	Glomerporphyritic with olivine.

Groundmass: Hyallophytic~intersertal texture. Most part is composed from turbid glass and vesicles. Vesicles are partly occupied with foraminifera and calcite.

Mineral	Texture	Size (mm)	Volume (%)	Description
Olivine	Granular, prismatic	0.05-0.2	5	Associating with fan-like clinopyroxene.
Clinopyroxene	Fan-like	0.05-0.6	~30	Fan-like microlite. High optical dispersion.
Plagioclase	Prismatic	~0.8(Length)	10	Acicular and thin prismatic. Partly glomerporphyritic with pyroxene.
Glass	Turbid	-	~30	
Calcite	Irregular	-	2	
Foraminifera	Rounded	0.05-0.15		
Vesicle		0.05-0.2	~30	

Alteration: Not altered

Mineral	Texture	Size (mm)	Volume (%)	Description



No.6

Sample Number:06_04SFAD04-TS02

Rock type: olivine basalt

Naked eye observation: Dark gray, fine grained, homogeneous and vesicular volcanic rock. Small amount of plagioclase phenocryst is recognized. Magnetism is high.

Microscopic observation

Texture: Intersertal texture. Vesicles occupy 10-20% of groundmass and are heterogeneously distributed. Microphenocryst of olivine and plagioclase are observed.

Phenocryst

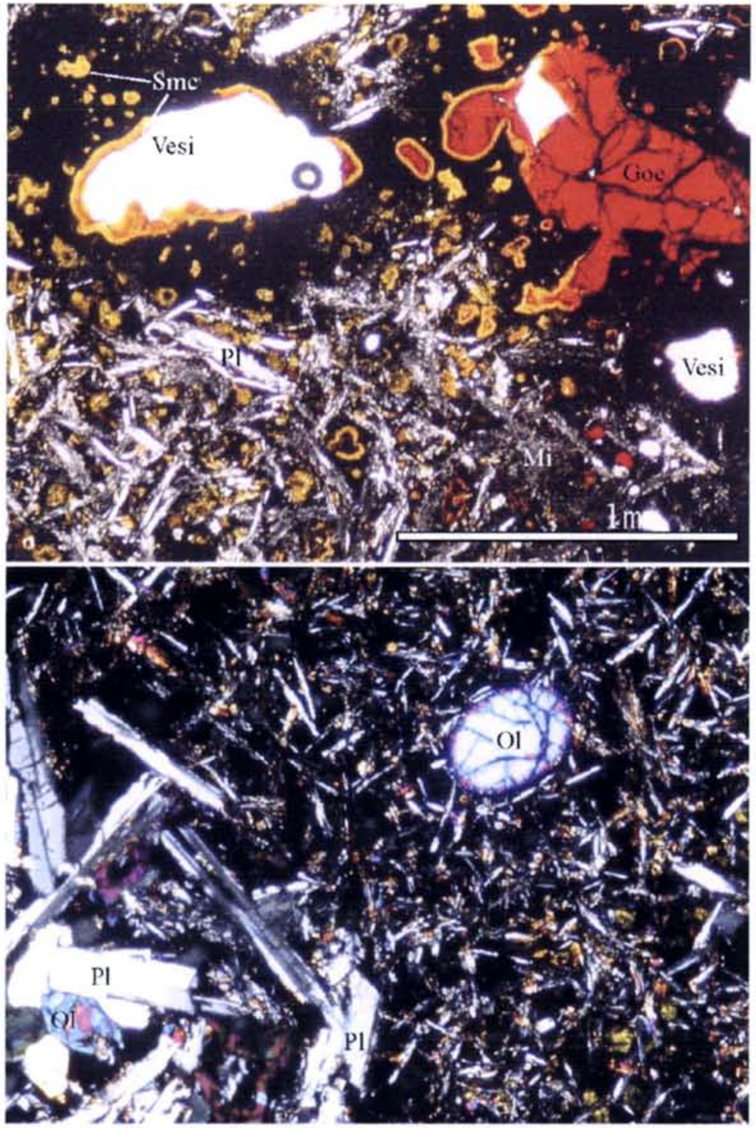
Mineral	Texture	Size(mm)	Volume (%)	Description
Olivine	Prismatic, oval	0.3-0.5	~2	Many crystals are skeletal.
Plagioclase	Prismatic	0.6	~3	Partly included by olivine.

Groundmass: Intersertal texture. Mainly composed of plagioclase lath, fan-like clinopyroxene and turbid glass.

Mineral	Texture	Size (mm)	Volume (%)	Description
Olivine	Granular	0.02-0.2	~2	
Clinopyroxene	Prismatic	0.05-0.2	~30	Fan-like microlite and clear crystal.
Plagioclase	Prismatic~acicular	0.2-0.5	10	Many shows swallow-tail shape.
Magnetite	Dendritic	0.002	5	Associating with glass and clinopyroxene.
Glass	Turbid	-	~40	Dark brown and turbid.
Vesicle	Rounded~irregular	0.2-0.4	10-20	

Alteration: Clay minerals and goethite partly occupying vesicle

Mineral	Texture	Size (mm)	Volume (%)	Description
Smectite	Film	0.05 (Thickness)	~5	Deep yellow. Formed along vesicle inner wall. Optically positive.
Goethite	Tabular	0.1-0.6	~5	Red. Showing narrow birefringence. Occupying vesicle.



No.7

Sample Number: 07_04SFAD05-TS01

Rock type: Aphyric basalt

Naked eye observation: Dark gray, fine grained, homogeneous and vesicular volcanic rock. Small amount of plagioclase phenocryst is recognized. Magnetism is high.

Microscopic observation

Texture: Hyaloophitic texture. Vesicles occupy 30% of groundmass.

Phenocryst

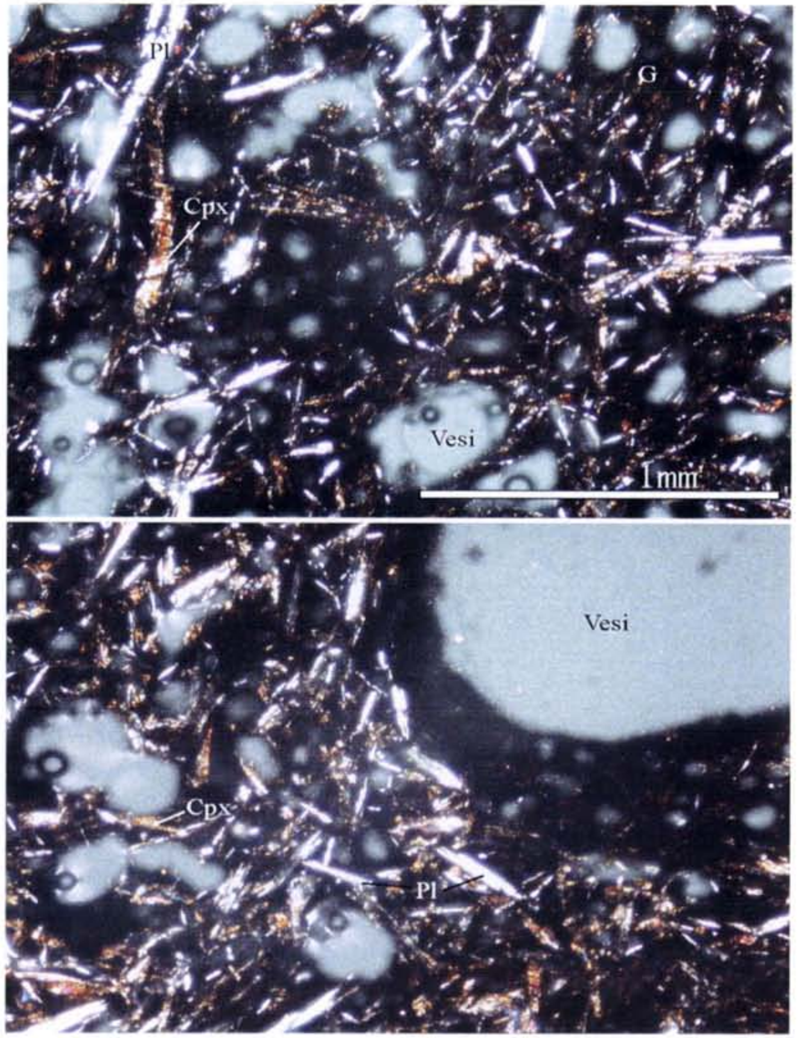
Mineral	Texture	Size(mm)	Volume (%)	Description
Plagioclase	Prismatic	0.6(Length)	~2	Thin. Irregular edge. Swallow-tail shape.

Groundmass: Mainly composed from brown turbid glass with microlite(clinopyroxene) and acicular plagioclase. Vesicular.

Mineral	Texture	Size (mm)	Volume (%)	Description
Plagioclase	Acicular, prismatic	~0.3(Length)	10	Edge of crystal is swallow-tail shape.
Clinopyroxene	Fan-like	~0.4(Length)	20	Microlite. Thin acicular.
Glass	Turbid		40-50	Brown. Turbid.
Magnetite	Dendritic	Micro	<2	Associating with clinopyroxene. Also formed along plagioclase rim.
Vesicle	Irregular	0.1-2.0	20-30	Variable size. Irregular.

Alteration: Not altered

Mineral	Texture	Size (mm)	Volume (%)	Description



No.8

Sample Number:08_04SFAD05-TS02

Rock type:Aphyric basalt

Naked eye observation: Dark gray, fine grained, homogeneous and vesicular volcanic rock. Small amount of plagioclase phenocryst is recognized. Magnetism is high.

Microscopic observation

Texture: Hyaloophitic texture. Mainly composed from turbid glass with microlite (clinopyroxene) and acicular plagioclase. Vesicular.

Phenocryst

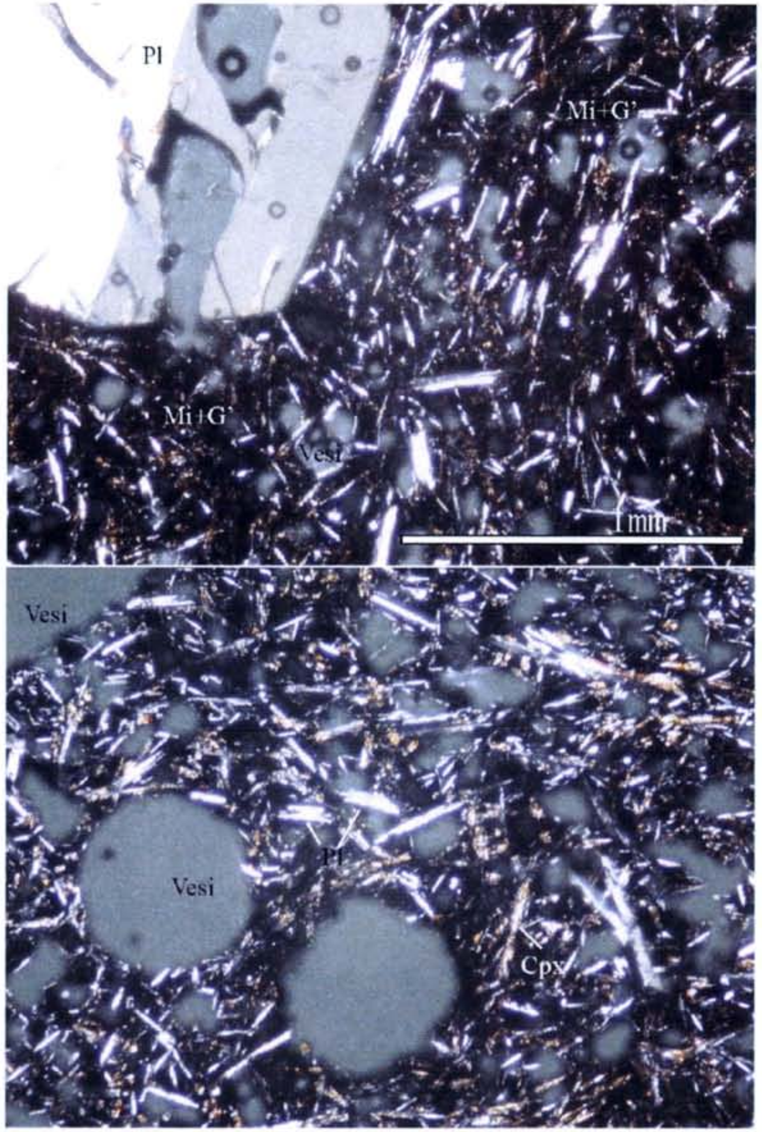
Mineral	Texture	Size(mm)	Volume (%)	Description
Plagioclase	Prismatic	2.5	<1	Only one hollow crystal is observed. Subhedral and acicular.

Groundmass: Mainly composed from brown turbid glass with microlite(clinopyroxene) and acicular plagioclase.

Mineral	Texture	Size (mm)	Volume (%)	Description
Plagioclase	Acicular	0.2(Length)	10	Edge of crystal is swallow-tail shape
Clinopyroxene	Fan-like	0.2(Length)	20	High optical dispersion and oblique extinction.
Magnetite	Dendritic	Micro	~1	Crystallizing along clinopyroxene microlite surface. Dendritic
Glass	Turbid	-	40	Turbid. Brown.
Vesicle	Oval-irregular	0.05-2.0	20-30	Small oval type (~0.1mm in diameter) and irregular type (1-2mm in diameter)

Alteration: Not altered

Mineral	Texture	Size (mm)	Volume (%)	Description



5-2 2.Whole Rock Chemistry of Igneous Rocks

2-1 Samples

Whole rock chemical analyses were conducted for volcanic rocks using the same samples as microscopic observations (Table 1).

Table 1 Rock Samples for Chemical Analyses

Area	Sampling No.	Depth (m)	No. of Individual Sample	Lithology	Sample No.
ERZ A	04SFAD02	1956-1803	C3	vitric surface of basalt	04SFAD02 CA01
			C5	fragments of quenched basalt	04SFAD02 CA02
	04SFAD03	1954-1801	C5	small pillow or tube	04SFAD03 CA01
			C6	crust of lava flow surface	04SFAD03 CA02
	04SFAD04	1941-1925	C1	fragments of autobrecciated	04SFAD04 CA01
			C3	part of pillow lava	04SFAD04 CA02
	04SFAD05	2072-1955	C2	fragments of autobrecciated	04SFAD05 CA01
			C5	part of pillow lava	04SFAD05 CA02

2-2 Analyzed Elements and Analytical Methods

A total of 44 elements, including major elements, trace elements and REE, were analyzed for whole rock chemical analyses. Analytical elements, analytical methods and detection limits are given on Tables 2. The chemical analyses were conducted at ALS Chemex, Canada. Before the chemical analyses desalination of the samples were conducted by supersonic washer using the deionized water for twenty four hours, repeating three times.

Table 2 Analytical Methods and Analyzed Elements

Analyzed Elements (lower limit-upper limit)	Analytical Method
SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5 (0.01-100%)	ICP-AES
FeO (0.1-100%)	Titration
H_2O^+ (0.1-100%), H_2O^- (0.1-100%)	Gravitational Method
CO_2 (0.05-100%)	LECO
LOI (0.01-100%)	After fusing at 1000 deg.C gravitationally determined
Rb (0.2ppm-), Ba (1ppm-), Zr (1ppm-), Cs (0.05ppm-), Y, Ta, U (0.1ppm-)	ICP-MS
Sr (0.2ppm-), V (1ppm-), Nb, Hf, Th (0.1ppm-), Pb, Ni (0.5ppm-)	
Pr, Sm, Gd, Dy, Tb, Ho, Er, Yb, Eu, Tm, Lu (0.01ppm-)	

2-3 Analytical Results

The results of chemical analyses are shown on Table 3.

Table 3 Results of Whole rock Chmical Analyses

Area	Sampling No.	Depth (m)	No. of Individual Sample	Lithology	Sample No.	SiO_2	TiO_2	Al_2O_3	FeO	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	H_2O^+	H_2O^-	CO_2	FeO*	Mg#
						%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	
ERZ A	04SFAD02	1956-1803	C3	vitric surface of basalt	04SFAD02 CA01	50.12	1.421	14.04	9.32	1.77	0.197	7.39	11.49	2.62	0.09	0.12	1.23	99.81	0.20	0.77	<d.l.	10.91	0.55
			C5	fragments of quenched basalt	04SFAD02 CA02	50.21	1.446	13.99	9.47	1.88	0.192	7.33	11.42	2.63	0.12	0.12	0.87	99.68	0.07	0.62	<d.l.	11.16	0.54
	04SFAD03	1954-1801	C5	small pillow or tube	04SFAD03 CA01	50.48	1.435	14.01	9.52	1.91	0.189	7.32	11.43	2.64	0.14	0.10	0.70	99.87	0.01	0.73	<d.l.	11.24	0.54
			C6	crust of lava flow surface	04SFAD03 CA02	50.28	1.433	14.04	9.12	2.14	0.201	7.23	11.50	2.66	0.14	0.12	0.81	99.68	0.09	0.96	<d.l.	11.05	0.54
	04SFAD04	1941-1925	C1	fragments of autobrecciated lava	04SFAD04 CA01	51.32	1.809	13.91	8.23	3.35	0.221	5.00	8.74	3.27	0.43	0.21	3.02	99.51	0.65	2.50	<d.l.	11.24	0.44
			C3	part of pillow lava	04SFAD04 CA02	48.54	2.282	12.54	10.48	3.72	0.229	4.81	8.92	3.06	0.36	0.23	4.73	99.90	0.66	4.55	<d.l.	13.83	0.38
	04SFAD05	2072-1955	C2	fragments of autobrecciated lava	04SFAD05 CA01	55.42	1.342	14.85	7.30	2.19	0.163	4.33	8.16	3.58	0.41	0.21	1.85	99.80	0.51	1.44	<d.l.	9.27	0.45
			C5	part of pillow lava	04SFAD05 CA02	54.63	1.290	14.60	7.27	2.05	0.173	4.22	7.99	3.57	0.40	0.21	3.01	99.42	0.84	2.53	<d.l.	9.11	0.45
				Jb-3		51.36	1.393	17.17	7.63	3.31	0.174	5.13	9.67	2.76	0.76	0.28	0.29	99.93	0.21	0.60	<d.l.	10.61	0.46

Area	Sampling No.	Depth (m)	No. of Individual Sample	Lithology	Sample No.	V	Ni	Th	U	Zr	Hf	Nb	Ta	Cs	Ba	Rb	Sr	Pb	Y
						ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
ERZ A	04SFAD02	1956-1803	C3	vitric surface of basalt	04SFAD02 CA01	289	66.0	0.5	-0.1	93.2	3.5	2.6	0.15	1.8	22	<d.l.	86.6	1.7	27.6
			C5	fragments of quenched basalt	04SFAD02 CA02	329	72.0	0.3	-0.1	104.0	3.1	2.8	0.17	3.2	23	0.4	97.0	0.8	36.2
	04SFAD03	1954-1801	C5	small pillow or tube	04SFAD03 CA01	332	75.4	0.3	-0.1	107.0	3.0	2.7	0.14	3.2	20	0.2	92.1	0.6	35.3
			C6	crust of lava flow surface	04SFAD03 CA02	308	68.1	0.3	0.1	94.1	2.7	2.6	0.27	3.0	21	0.8	89.6	3.1	32.5
	04SFAD04	1941-1925	C1	fragments of autobrecciated lava	04SFAD04 CA01	299	54.6	0.7	0.4	184.6	4.9	4.7	0.43	1.9	72	<d.l.	112.5	3.8	42.2
			C3	part of pillow lava	04SFAD04 CA02	372	46.2	0.4	0.2	176.7	4.7	4.2	0.29	2.0	39	<d.l.	88.7	1.9	45.9
	04SFAD05	2072-1955	C2	fragments of autobrecciated lava	04SFAD05 CA01	237	37.8	0.5	0.4	176.6	4.6	5.5	0.60	1.9	63	<d.l.	211.1	1.6	30.4
			C5	part of pillow lava	04SFAD05 CA02	201	35.4	0.5	0.3	157.7	4.0	5.2	0.49	2.3	55	<d.l.	185.4	1.3	25.6
				Jb-3		396	42.4	0.7	0.6	93.6	2.8	3.1	0.78	2.6	269	1.7	419.0	5.3	17.9

Area	Sampling No.	Depth (m)	No. of Individual Sample	Lithology	Sample No.	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
						ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
ERZ A	04SFAD02	1956-1803	C3	vitric surface of basalt	04SFAD02 CA01	3.34	10.04	1.72	9.90	3.25	1.34	5.10	0.96	6.18	1.31	3.83	0.570	3.59	0.519
			C5	fragments of quenched basalt	04SFAD02 CA02	3.43	10.36	1.75	10.43	3.55	1.39	5.28	1.00	6.55	1.37	4.10	0.609	3.82	0.549
	04SFAD03	1954-1801	C5	small pillow or tube	04SFAD03 CA01	3.25	9.81	1.67	9.89	3.41	1.37	5.10	0.96	6.18	1.30	3.93	0.583	3.67	0.531
			C6	crust of lava flow surface	04SFAD03 CA02	3.18	9.69	1.69	9.98	3.36	1.38	5.12	0.97	6.32	1.34	4.00	0.603	3.79	0.530
	04SFAD04	1941-1925	C1	fragments of autobrecciated lava	04SFAD04 CA01	7.92	19.65	3.08	17.01	5.37	1.94	7.95	1.52	9.27	1.93	5.85	0.885	5.58	0.805
			C3	part of pillow lava	04SFAD04 CA02	6.25	17.65	2.96	16.56	5.41	2.02	8.32	1.59	9.91	2.07	6.18	0.926	5.93	0.862
	04SFAD05	2072-1955	C2	fragments of autobrecciated lava	04SFAD05 CA01	9.81	23.05	3.32	16.50	4.87	1.69	6.57	1.24	7.53	1.59	4.74	0.714	4.50	0.649
			C5	part of pillow lava	04SFAD05 CA02	9.59	22.48	3.19	15.43	4.57	1.64	6.07	1.13	7.30	1.51	4.54	0.687	4.41	0.641
				Jb-3		9.21	22.22	3.28	16.13	4.25	1.38	4.93	0.83	4.76	0.95	2.73	0.401	2.52	0.371

2-4 Interpretation of the Results

2-4-1 Norm calculations

The norm calculation was conducted using the analytical results and the results were shown on Table 4.

The samples collected at 04SFAD02 and 04SFAD03 are silica undersaturated rock with normative olivine and clinopyroxene, while samples collected form the at 04SFAD04 and 04SFAD005 are silica saturated rock with normative quartz. All the samples show high amount of normative pyroxenes and feldspar reaching more than 80%.

The analytical results were plotted to various diagrams for further discussion of classification of the rocks and tectonic setting of their origin.

2-4-2 Classification Diagrams($SiO_2-(Na_2O+K_2O)$, SiO_2-K_2O, AFM Diagrams)

The analytical results were normalizing to 100% by the total of ten major elements, they were plotted to $SiO_2-(Na_2O+K_2O)$, SiO_2-K_2O, AFM diagrams for discrimination of rock type.(Figures 1 to 3). According to the classification of Cox et al. (1979) all the samples collected at 04SFAD02 and 04SFAD03 and 04SFAD04CA02 are classified to basalt. While, 04SFAD04CA01 and the samples collected at 04SFAD05 are, respectively, classified into basaltic andesite and andesite (Figure 1). The all the samples are plotted in the area of low-K series volcanic rocks (Figure 2). Since the samples do not show a clear trend of differentiation, magmatic series can not be identified for these rocks (figure 3).

2-4-3 Tectonic Setting (Nb-Zr-Y, Ti-V Diagrams)

For considering the tectonic setting of origin of these rock analytical results were plotted on Nb-Zr-Y and Ti-V diagrams (Figures 4 and 5). Since these diagrams are only applicable for basaltic rocks, 04SFAD005 with andesitic composition was plotted only for reference. On the Nb-Zr-Y Diagrams which discriminate MORBs from within-plate basalt (Meschede, 1986, Figure 4), all the samples collected at 04SFAD02, 03 and 04 have similar composition to N-MORB and volcanic arc basalt. On the Ti-V diagram (Figure 5), all the samples collected at 04SFAD02 and 03 are plotted in the fields of MORB or BAB (Back arc basalt), while, samples of 04SFAD04 are plotted in the fileds of MORB or BAB and continental flood basalt.

2-4-4 Spidregram (normalized to N-MORB)

The analytical results are normalized to N-MORB and plotted to the spidergram (Figure 6a). For references typical basaltic rock from various tectonic settings were shown in Figure 6b using the data of Sun and McDonough (1989) and Shuutou and Gorai (1997). The samples of 04SFAD02 and 04SFAD03 show more or less similar concentrations and patterns to those of N-MORB except Ba. The concentrations and pattern are similar for samples of 04SFAD04 and 04SFAD05. Considering samples of 04SFAD05 are andesite, samples of 04SFAD04 with basaltic compositions are relatively enrich in LIL and HFS. The patterns of 04SFAD04 are similar to those of T-MORB (Transitional MORB), OIT (Oceanic Island Tholeiite) and WPT (Within Plate Tholeiite_

2-4-5 REE Diagram (normalized to N-MORB)

The analytical results are normalized to N-MORB of Sun and McDonough (1989) and REE diagram was drawn (Figure 7a). For references typical basaltic rock from various tectonic settings were shown in Figure 7b using the data of Sun and McDonough (1989) and Shuutou and Gorai (1997).

The samples collected at 04SFAD02 and 04SFAD03 show similar REE concentrations and patterns to those of N-MORB. The samples of 04SFAD05 have flat patterns of MREE (Middle Rare Earth, Sm~Ho) and HREE(Heavy Rare Earth Element, Er~Lu) and are very enriched in LREE (Light Rare Earth、La~Nd). The patters of 04SFAD04 samples are similar to that of T-MORB showing flat pattern with slightly declined LREE.

2-5 Considerations

The all diagrams (Figures 4 to 7) show that the samples collected at 04SFAD02 and 04SFAD03 have similar chemical composition to that of MORB. The low K nature of these rocks conforms with the chemical nature of N-MORB. These samples are olivine basalt originated form the similar tectonic setting to the speeding axis of the mid-oceanic ridge.

The samples collected at 04SFAD04 are silica saturated basalt to basaltic andesite, and they show chemical characteristic different form N-MORB, rather similar to OIT, T-MORB, WPT (Figures 5 to 7). But their REE patterns do not show clear enrichment of LREE, which is characteristic feature of plume related rock such as E-MORB and OIT. The most probable basaltic type for these rocks is T-MORB slightly related to plume.

The silica saturated andesite of 04SFAD05 are unusual rock for oceanic environment. Considering the low Ti despite of differentiated rock and enrichment of LREE, the possible tectonic setting for these rocks is newly born oceanic arc.

Table 4 Calculated Normal compositions

Sampling No.	Lithology	Sample No.	Ol	Qz	Hy	Di	Or	Ab	An	Mt	Ap	Il	Total	Hy+Di	Or+Ab+An	Py+Fld
04SFAD02	vitric surface of basalt	04SFAD02 CA01	1.4	0.0	18.4	24.8	0.5	22.5	26.7	2.6	0.3	2.7	99.9	43.2	49.7	92.9
	fragments of quenched basalt	04SFAD02 CA02	1.1	0.0	18.7	24.7	0.7	22.5	26.3	2.8	0.3	2.8	99.9	43.4	49.6	93.0
04SFAD03	small pillow or tube	04SFAD03 CA01	0.9	0.0	18.9	24.8	0.8	22.5	26.2	2.8	0.2	2.7	99.9	43.7	49.5	93.2
	crust of lava flow surface	04SFAD03 CA02	0.5	0.0	18.4	25.1	0.8	22.8	26.3	3.1	0.3	2.8	99.9	43.4	49.9	93.3
04SFAD04	fragments of autobrecciated lava	04SFAD04 CA01	0.0	5.2	14.6	16.9	2.6	28.7	22.8	5.1	0.5	3.6	99.9	31.5	54.1	85.6
	part of pillow lava	04SFAD04 CA02	0.0	3.0	16.0	20.3	2.2	27.2	20.4	5.6	0.6	4.6	99.9	36.3	49.8	86.1
04SFAD05	fragments of autobrecciated lava	04SFAD05 CA01	0.0	8.9	14.2	13.3	2.5	30.9	23.7	3.2	0.5	2.6	99.9	27.6	57.1	84.7
	part of pillow lava	04SFAD05 CA02	0.0	8.7	14.5	13.4	2.5	31.3	23.5	3.1	0.5	2.5	99.9	27.8	57.3	85.1

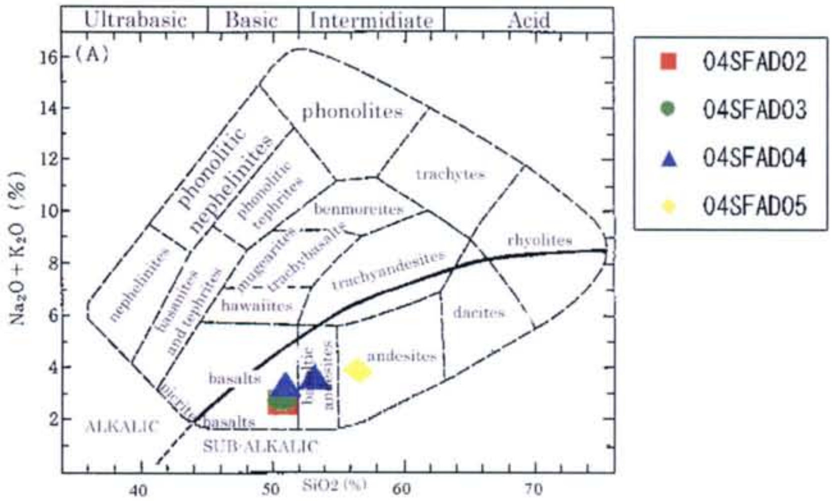


Fig1 Nomenclature of normal (i.e. non-potassic) igneous rocks after Cox et al.(1979). The dividing line between alkalic and sub-alkalic magma series is from Miyashiro (1978).

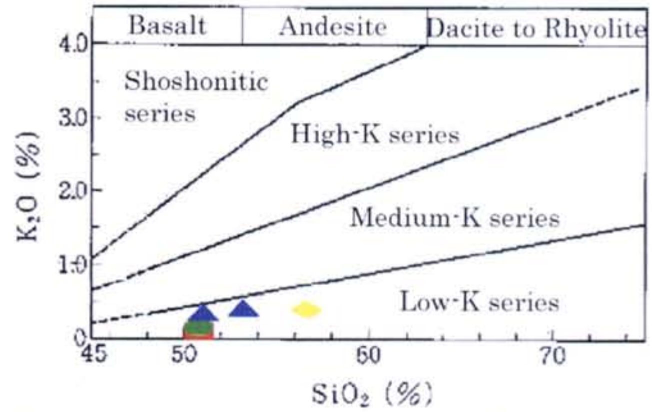


Fig2 Classification of alkalic and sub-alkalic volcanic rocks in terms of wt.% K2O versus wt.% SiO2 after Peccerillo and Taylor (1976).

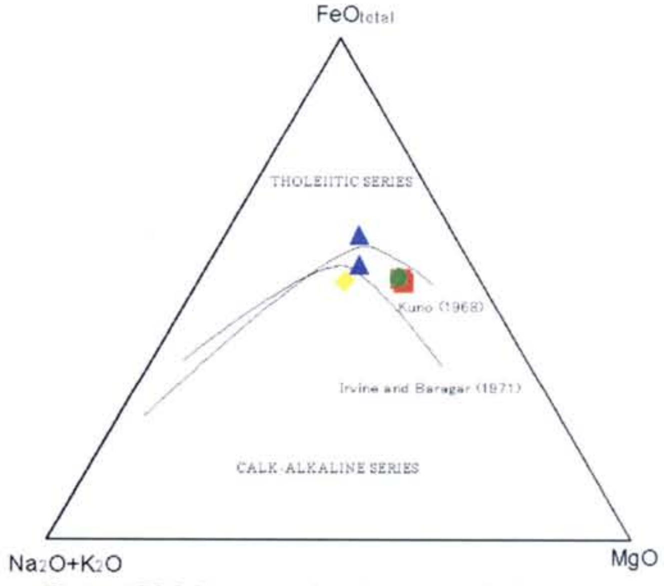


Fig3 AFM diagram showing typical tholeiitic and calc-alkaline differentiation trends.

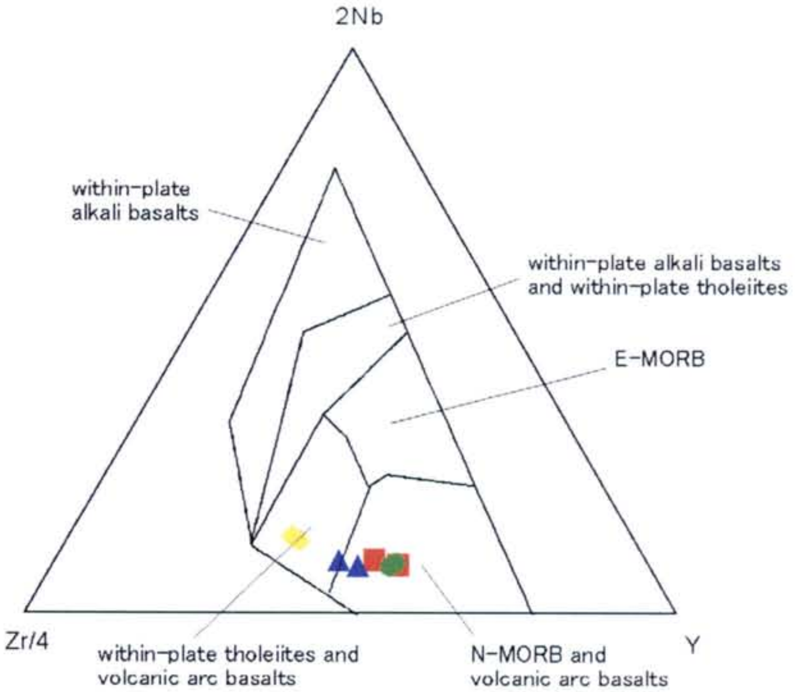


Fig4 2Nb-Zr/4-Y tectonomagmatic discrimination diagram for basaltic rocks (after Meschede 1986).

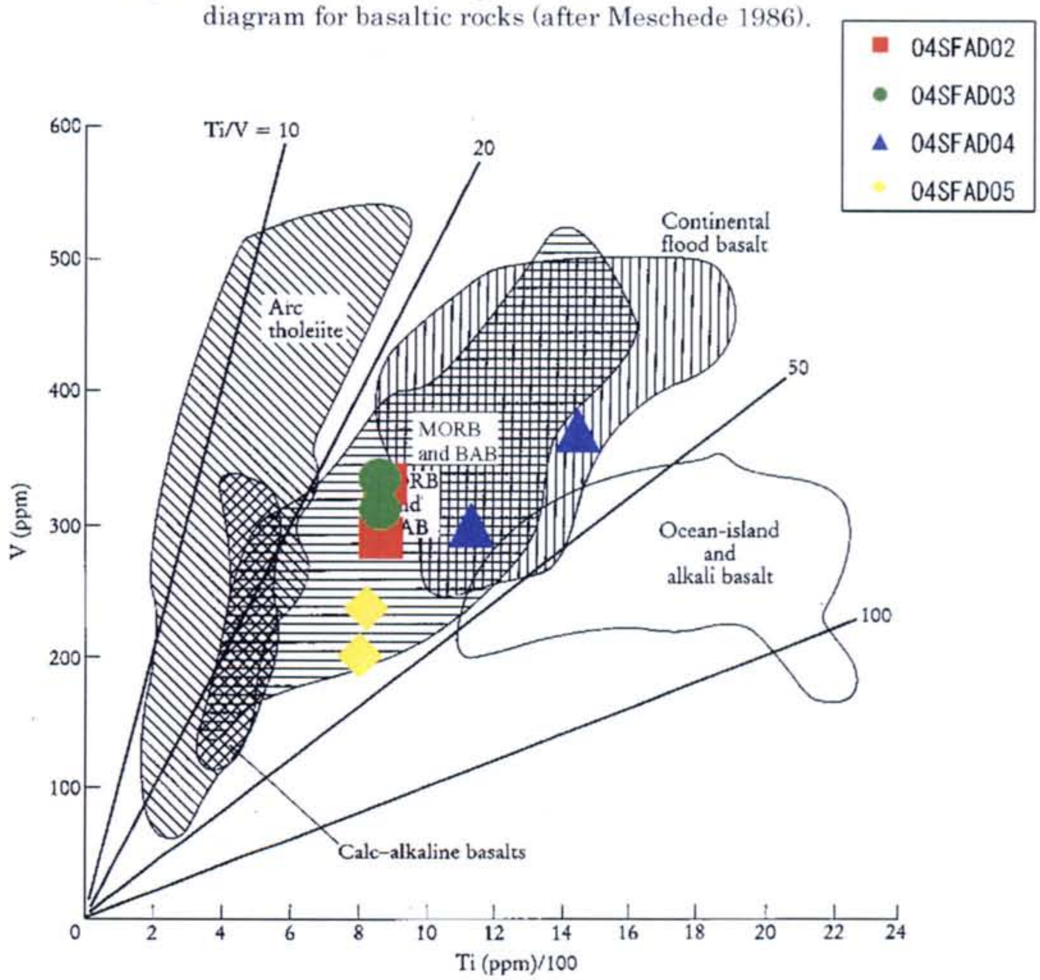


Fig5 Ti/1000 versus V (ppm) diagram, showing the discrimination of basaltic rocks after Shervais (1982).
BAB : Back-Arc Basin basalt

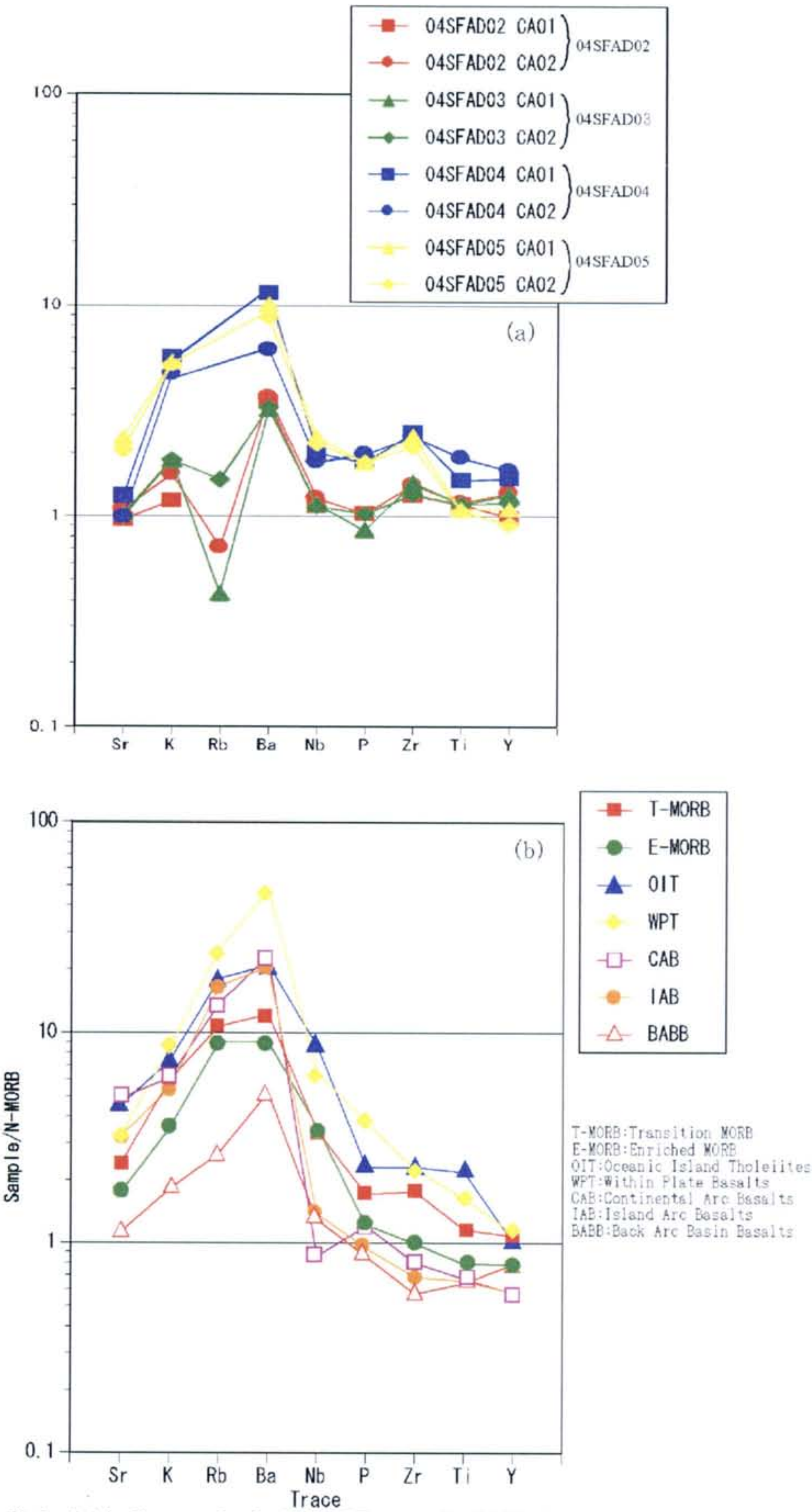
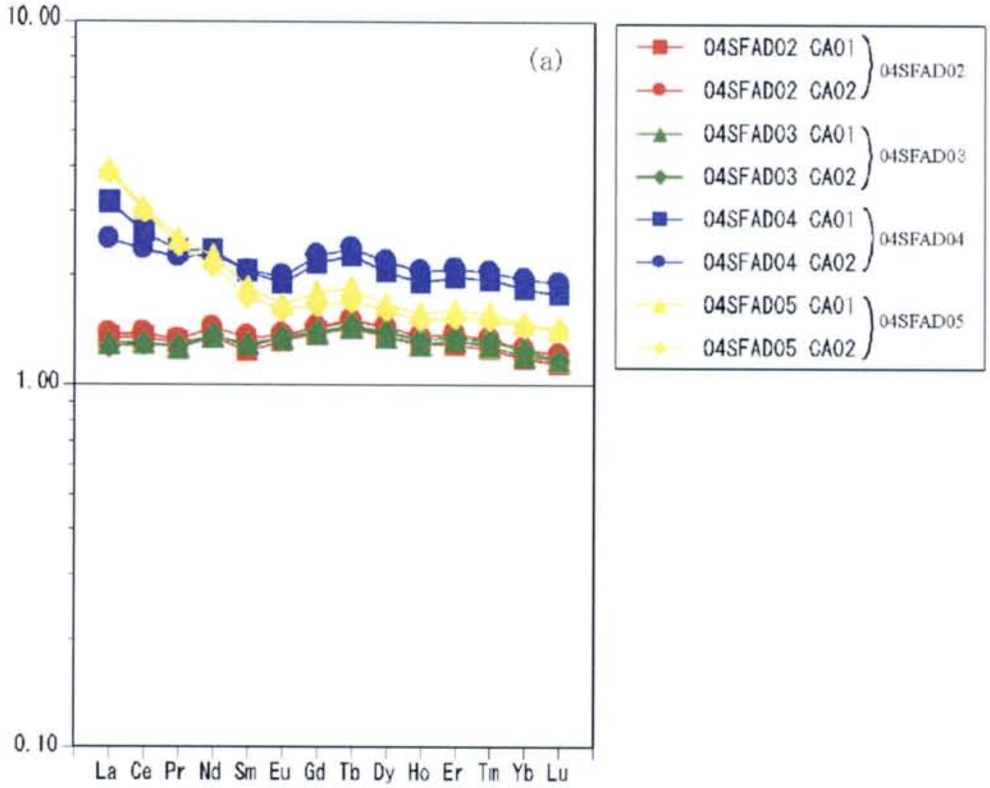


Fig6 Spiderdiagram for the N-MORB normalized LIL elements.
(a) Patterns for samples from the Fiji water
(b) Typical patterns for basalts
(N-MORB, E-MORB: Sun and McDonough, 1989
Others: Shuto and Gorai, 1997)



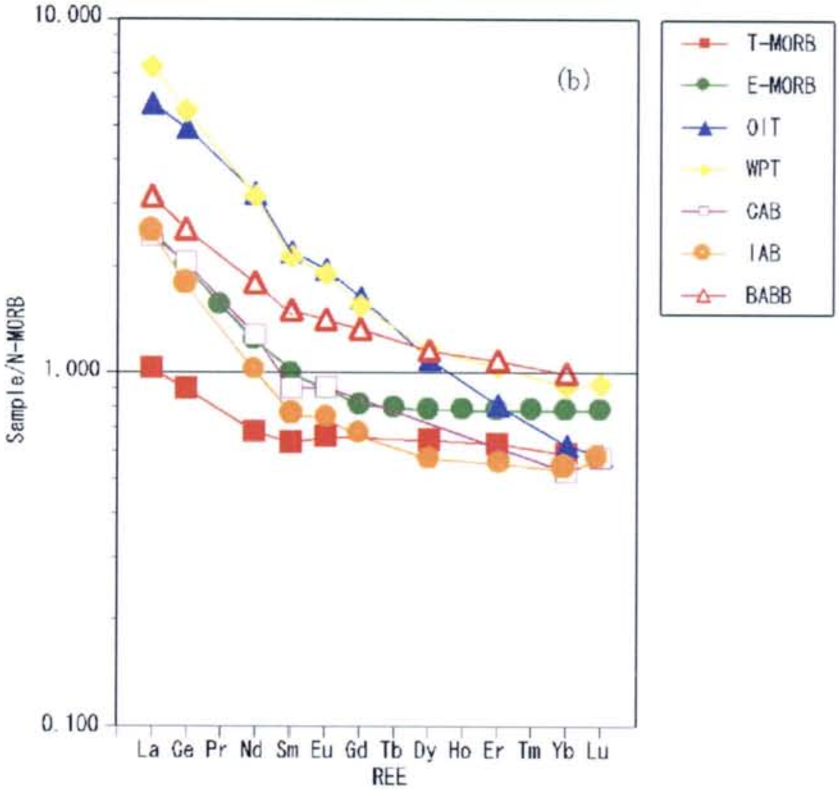


Fig7 N-MORB normalized REE patterns
(a) Patterns for samples from Fiji water
(b) Typical patterns for basalts
(N and E-MORB : Sun and McDonough, 1989
Others : Shuto and Gorai, 1997)

5-2 3. K-Ar Dating of Igneous Rocks

3-1 Samples

One sample was chosen from each sampling location and age determination by K-Ar was conducted for four samples from four AD sampling locations in the ERZ A (Table 1).

Table 1 Samples for K-Ar Age Determination

Sample No.	K (%)	Ar_{rad} (nl/g)	$^{40}Ar_{air}$ (%)	Age (Ma)
04SFAD02 KR01	0.088	0.504	81.6	144.3+6.8
04SFAD03 KR01	0.061	0.172	86.2	72.4+6.2
04SFAD04 KR01	0.273	0.032	96.5	3.1+1.6
04SFAD05 KR01	0.342	0.112	95.9	8.5+1.5
Reanalyses				
04SFAD02 KR01rep	0.089	0.513	81.9	145.0+4.6
04SFAD03 KR01rep	0.066	0.195	53.5	76.0+4.1

K : total K of sample

$^{40}Ar_{rad}$: radiogenetic ^{40}Ar of sample

$^{40}Ar_{air}$: present ^{40}Ar of air

3-2 Analytical Methods

The age determination by K-Ar method was conducted by Activation Laboratories Ltd, Canada. The analyses of six samples were carried out after desalination treatment and pulverization.

The K concentration was performed by ICP (Thermo Jarrell Ash, Enviro II) and the argon analysis was performed using the isotope dilution procedure on noble gas mass spectrometer.

For obtaining the age, following equation was used.

$$t=1/(\lambda_\beta+\lambda_e)\ln((^{40}Ar_{rad}\cdot(\lambda_\beta+\lambda_e))/(^{40}K\cdot\lambda_e)+1)$$

where:

λ_β	: decay constant of ^{40}K to ^{40}Ca
λ_e	: decay constant of ^{40}K to ^{40}Ar
$^{40}Ar_{rad}$	: radiogenetic ^{40}Ar of sample
^{40}K	: present ^{40}K of sample

3-3 Analytical Results

The results are shown in Table 7. Although four samples were collected from similar geological environment, the samples 04SFAD02 KR01 and 04SFAD03 KR01 showed very unexpectedly old ages different from other two samples. The analyses of these two samples were conducted again, but similar ages to those of first analyses were obtained.

Table 2 Results of K-Ar dating

Sample No.	K(%)	Ar_{rad} (nl/g)	$^{40}Ar_{air}$ (%)	Age (Ma)
04SFAD02 KR01	0.088	0.504	81.6	144.3+6.8
04SFAD03 KR01	0.061	0.172	86.2	72.4+6.2
04SFAD04 KR01	0.273	0.032	96.5	3.1+1.6
04SFAD05 KR01	0.342	0.112	95.9	8.5+1.5
Reanalyses				
04SFAD02 KR01rep	0.089	0.513	81.9	145.0+4.6
04SFAD03 KR01rep	0.066	0.195	53.5	76.0+4.1

K: total K of sample

$^{40}Ar_{rad}$: radiogenetic ^{40}Ar of sample

$^{40}Ar_{air}$: present ^{40}Ar of air

3-4 Considerations

A wide range of ages, 3.1+/-1.6Ma to 144.3+/-6.8Ma, was obtained from K-Ar dating of 4 basaltic lava samples. The reasons for this are probably because analyzed samples are pillow lavas consisting of inhomogeneous materials including vitric parts and obtained ages were affected by excess ^{40}Ar.

Appendix 5

Laboratory Works 5－3

1. X-ray Diffraction of Alteration Products
2. Ore Analysis
3. Chemistry of sediments
4. Microfossils in sediments

5-3 1. X-Ray Diffraction of Alteration Products

1-1 Samples for X-Ray Diffraction Analyses

The X-ray diffraction analyses were conducted for altered rock and sediments for characterizing alteration and identifying some of the minerals (Table1).

Table 1 Sample List of X-ray Diffraction Analysis

Area	Sample No.	Depth(m)	Sampling Depth / No. of Individual Sample	Description	Sample No.
Central Hill	04SFFPG01	1,971		white vein penetrating serpentinite	04SFFPG01 XRD01
	04SFFPG03	1,968		black altered part of serpentinite	04SFFPG03 XRD01
				black precipitates on surface	04SFFPG03 XRD02
				detrital sandy clay	04SFFPG03 XRD03
				pale bluish gray clay	04SFFPG03 XRD04
				dark gray pebble in pale bluish gray clay	04SFFPG03 XRD05
				reddish brown precipitate	04SFFPG03 XRD06
				white acicular crystals in druses occur in bluish gray clayey part	04SFFPG03 XRD07
	04SFMC11	1,946	0.00	black and white clayey precipitates	04SFMC11 XRD01
			0.15-0.18	foraminifera sand	04SFMC11 XRD02
ERZ A	04SFAD02	1,956→1,803		greenish altered part of lava flow	04SFAD02 XRD01
	04SFAD02	1,956→1,803	C10	altered basalt	04SFAD02C10 XRD01
					04SFAD02C10 XRD02
					04SFAD02C10 XRD03
			C11	altered basalt	04SFAD02C11 XRD04
					04SFAD02C11 XRD05

1-2 Analytical Methods

The X-ray diffraction analyses were conducted by Prof. K. Watanabe at Kyushu University using x-ray diffractometer of Riggaku RINT2100. Powder patterns were obtained by Cu Kα radiation scanning 2-70 degree at scan speed of 2 degree per a minute. The examined samples includes nonoriented and oriented powders and treated powders by HCl and ethylene glycol.

1-3 Results of Analyses

The results of X-ray diffraction analyses are given on Table 2. The relative abundance of minerals is show as quartz index. The quartz index was proportionally obtained, as given below, considering the diffraction intensity of 101 plain of standard quartz as 100%

Quartz Index of Mineral A = (Intensity of the maximum peak of Mineral A/Intensity of 101 plain of standard quartz) x 100

1-4 Considerations

1-4-1 Central Hill

(1) 04SFFPG01

-XRD01 (white vein penetrating serpentinite): Aragonite peak was obtained and the vein penetrating serpentinite consists of aragonite.

(2) 04SFFPG03

-XRD01 (black altered part of serpentinite): Serpentine, calcite, aragonite, chromite and brucite were identified. These minerals are alteration products of the ultramafic rocks.

-XRD02 (black precipitates on surface): Peaks of quartz, albite and calcite were obtained. The reason for black color is not unknown, but they are mineral assemblages of altered felsic materials.

-XRD03 (detrital sandy clay): Tremolite, chlorite, serpentine and talc were identified. These are mineral assemblages of altered ultramafic rocks.

-XRD04 (pale bluish gray clay): Albite, tremolite, serpentine, calcite and aragonite were identified and this sample is considered to be alteration materials of ultramafic rocks.

-XRD05 (dark gray pebble in pale bluish gray clay): Serpentine, calcite, aragonite, chromite and pyrite were identified. These minerals suggest that the pebble is altered ultramafic rock..

-XRD06 (reddish brown precipitates): The mineral assemblages found by X-ray diffraction, such as serpentine, calcite, aragonite and chromite suggest this precipitates to be alteration materials of ultramafic rock.

-XRD07 (white acicular crystals in druses occur in bluish gray clayey part): Serpentine and aragonite were identified. The white acicular crystals are aragonite.

(3) 04SFMC11

-XRD01 (black and white clayey precipitates): Calcite, magnesite or rhodochrosite, aragonite and Todorokite were identified. The black precipitates are probably reflecting todorokite and the white precipitates consist of mixture of various carbonates.

-XRD02 (foraminifera sand): serpentine, calcite, magnesite or rhodochrosite, aragonite and todorokite were identified. The foraminifera sand consists of calcareous fragments of foraminifera, and alteration materials of ultramafic rocks are included in them.

1-4-2 ERZ A

(1) 04SFAD02

-XRD01 (greenish altered part of lava flow): Smectite was identified and green color reflects the semectite alteration of lava flow.

(2) 04SFAD02C10

-C10XRD01 (altered basalt): Smectite was identified. The basalt is altered to semectite.

-C10XRD02 (altered basalt): Peaks of smectite, serpentine and todorokite are obtained. This sample seems to be altered olivine basalt with coating of manganese oxides.

-C10XRD03 (altered basalt): Same as C10XRD02, semctite, serpentine and todorokite were identified. This sample seems to be altered olivine basalt with coating of manganese oxides.

(3) 04SFAD02C11

-C11XRD04 (altered basalt): Peaks of smectite and todorokite were obtained. This sample seems to be altered basalt with coating of manganese oxides.

-C11XRD05 (altered basalt): Same as C11XRD05, peaks of smectite and todorokite were obtained. This sample seems to be altered basalt with coating of manganese oxides

Table 2 Results of X-ray Diffraction Analysis

Area	Sampling No.	Sampling Depth / No. of Individual Sample	Description	Sample No.	Silicate							Carbonates			Other minerals				Remarks
					Silica Minerals	Feldspar	Others	Clay minerals											
					Quartz	Albite	Tremolite	Smectite	Chlorite	Serpentine	Talc	Calcite	Calcite(*1)	Aragonite	Chromite	Pyrite	Todorokite	Brucite	
Central Hill	04SFFPG01		white vein penetrating serpentinite	04SFFPG01 XRD01										14.6					
	04SFFPG03		black altered part of serpentinite	04SFFPG03 XRD01						0.7		0.4		5.9	0.4			0.3	
			black precipitates on surface	04SFFPG03 XRD02	0.4?	0.9						1.1							
			detrital sandy clay	04SFFPG03 XRD03			2.8		0.7	6.4	0.2?	10.0		0.7					
			pale bluish gray clay	04SFFPG03 XRD04		0.4?	0.1?			2.2		11.5		0.6					
			dark gray pebble in pale bluish gray clay	04SFFPG03 XRD05						1.7		0.3		7.2	0.9	1.0			
			reddish brown precipitates	04SFFPG03 XRD06						1.9		0.7		6.2	0.2				unknown peak d=2.01
			white acicular crystals in druses occur in bluish gray clayey part	04SFFPG03 XRD07						0.9				8.8					
	04SFMC11	0.00	black and white clayey precipitates	04SFMC11 XRD01								0.4	10.5	3.5			0.2?		
		0.15 -0.18	foraminifera sand	04SFMC11 XRD02						1.1		1.2	0.9	1.1			tr		
ERZ A	04SFAD02		greenish altered part of lava flow	04SFAD02 XRD01				1.2											unknown peak d=2.81
	04SFAD02	C10	altered basalt	04SFAD02 XRD01				0.2											
				04SFAD02 XRD02				tr		0.6							tr		
				04SFAD02 XRD03				tr		2.1							tr		
		C11	altered basalt	04SFAD02 XRD04				0.7									tr		
				04SFAD02 XRD05				0.4									tr		

numbers are given in %   calcite(*1) : calcite, manganous or magnesian   tr : identified only by oriented poeders

5-3 **2. Chemical Analyses of Altered Rocks**

2-1 Samples

Altered and discolored rocks of the Central Hill were selected for chemical analyses to characterize the alteration and possible mineralization of the area (Table 1).

Table 1 Sample List of Chemical Analysis

Area	Sample No.	Depth (m)	Lithology	Sample No.
Central Hill	04SFFPG01	1,971	black serpentinite	04SFFPG01 CR01
			yellowish brown serpentinite	04SFFPG01 CR02
	04SFFPG03	1,968	white alteration vein and serpentinite	04SFFPG03 CR01
			conglomerate with reddish brown precipitates	04SFFPG03 CR02
			bluish gray clayey materials	04SFFPG03 CR03

2-2 Analytical Methods and Elements

A total of 54 elements, including platinum group elements (PGE), Au, Ag and transition metallic elements, were analyzed. Analyzed elements, analytical methods, detection limits are given in Table 2. The chemical analyses were mainly conducted at ALS Chemex, Canada, except PGE and Au, which were analyzed in Genalysis Laboratory Service Pty. Ltd, Australia. Before the chemical analyses desalination of the samples were conducted by supersonic washer using the deionized water for twenty four hours, repeating three times.

2-3 Analytical Results

The analytical results are shown on Table 3.

Table 2 Analyzed Elements and Analytical Method

Analyzed Elements (lower limit-upper limit)	Analytical Method
Ag (1-1,000ppm), Cu (0.01-50%), Co (0.001-50%), Ni (0.01-50%), Pb (0.01-30%), Zn (0.01-30%), Fe (0.01-30%), As (0.01-30%), Cd (1ppm-10%), Sb (0.01-100%)	Atomic Absorption Spectrometer
Pt, Pd, Ru, Rh, Os, Ir, Au (1ppb-), Ag (5-3,500ppm)	Fire Assay+ICP-MS
S (0.01-50%)	Infrared Absorption Analysis
Hg (0.01-100ppm)	Cold Vapor-AAS
Fe (0.01-100%), Zn (0.01-100%)	Titration
Ti (0.005-10%), P (10-10,000ppm), Mn (5-10,000ppm), Cr, V (1-10,000ppm)	ICP-AES
Ba (10-10,000ppm), W (0.1-10,000ppm), Mo (0.05-10,000ppm), Be, Sb (0.05-1000ppm), Bi (0.01-10,000ppm)	ICP-AES and ICP-MS
Se (1-1,000ppm), La, Zr (0.5-500ppm), Li, Sn, Th (0.2-500ppm), Hf, Nb, Rb, U, Y (0.1-500ppm), Cs, Ga, Ge, Te (0.05-500ppm), Ta (0.05-100ppm), Tl (0.02-500ppm), Ce (0.01-500ppm), In (0.005-500ppm), Re (0.002-50ppm)	ICP-MS
H_2O^+ (0.01-100%), C (0.01-50%)	LECO
H_2O^- (0.01-100%)	After drying at 105 deg.C gravitationally determined
LOI (0.01-100%)	After fusing at 1000 deg.C gravitationally determined

2-4 Statistical Analyses

2-4-1 Univariant Analysis

For statistical Treatment analytical values less than detection limit are treated as a half value of detection limit. The statistical values, such as maximum, minimum, average, standard deviation and coefficient of variation, are given on Table 4. No significant differences of concentration between sampling locations 04SFFPG01 and 04SFFPG03 was observed except Mn which shows slightly higher average value in 04SFFPG03 than in 04SFFPG01.

2-4-2 Multi-variant Analyses

Correlation coefficients were calculated and non correlation test was carried out (Tables 5 and 6). As the results, HFS (Ti、Al、Mn、P、Th、と、Zr、Hf、Nb、Ta) and REE (La、Ce、Pr、Nd、Sm、Eu、Gd、Tb、Dy、Ho、Er、Tm、Yb、Lu) show good correlation. The HFS and REE are known to show similar behavior during episodes of magmatic and hydrothermal activities. The correlation coefficients obtained are reflecting this point. Si、Ti、Mn、V、Cr and Fe are included in serpentine and oxides included in serpentine, while Ca、P and C are included in carbonates.

2-4-3 REE Normalized Patterns

The REE of the analyzed samples were normalized to primordial mantle (McDonough et al., 1991) for serpentinite samples ((04SFFPG01 CR01,CR02 and 04SFFPG03 CR01) and to North American Standard Shale (Gromet et al., 1984) for conglomerate and clay sample. The REE normalized patters are shown in Figures 1 and 2.

Two serpentinite show similar REE pattern, showing high LREE, right side declining pattern. The concentrations of REE are less compared to the primordial mantle except La. Although these samples were strongly altered, chemical characteristics of low REE concentration less than primordial mantle and higher LREE are similar to those of forearc serpentine.

Conglomerate and clay samples shows lower concentrations of REE compared to the North American Standard Shale. Although the concentrations are low, 04SFFPG03CR02 show flat pattern of REE, showing similar concentration ratio of REE compared to those of the North American Standard Shale.

Table 3 Results of chemical analysis

Area	Sampling No.	Lithology	Sample No.	SiO_2	TiO_2	Al_2O_3	FeO	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^+	C	LOI	Total
				%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Central Hill	04SFFPG01	black serpentinite	04SFFPG01 CR01	32.30	0.01	0.28	3.55	3.60	0.06	33.10	9.50	0.07	0.02	0.02	9.94	2.05	15.50	98.01
		yellowish brown serpentinite	04SFFPG01 CR02	33.60	0.01	0.30	1.31	6.50	0.04	33.30	7.28	0.02	0.02	<d.l.	11.30	1.66	17.35	99.73
	04SFFPG03	white alteration vein and serpentinite	04SFFPG03 CR01	31.40	0.01	0.32	1.93	4.82	0.10	31.20	10.85	0.07	0.02	0.03	9.96	2.40	18.55	99.30
		conglomerate with reddish brown precipitates	04SFFPG03 CR02	34.30	0.06	0.70	0.51	8.20	0.50	35.40	3.75	0.09	0.03	0.10	12.05	0.82	15.35	98.99
		bluish gray clayey materials	04SFFPG03 CR03	31.10	0.01	0.38	2.91	3.54	0.05	32.20	11.25	0.08	0.01	0.03	10.10	2.48	16.50	98.06
		Dupricate	04SFFPG03 CR01	28.90	0.01	0.22	1.90	4.73	0.11	30.20	13.50	0.07	0.01	0.05	9.97		2.95	19.65

Area	Sampling No.	Lithology	Sample No.	Ti	V	Cr	Mn	Fe	Co	Ni	Ni	Cu	Zn	Th	U	Zr	Hf	Nb	Ta	Cs	Ba	Rb	Sr	Pb
				%	ppm	ppm	ppm	%	%	%	ppm	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%
Central Hill	04SFFPG01	black serpentinite	04SFFPG01 CR01	<d.l.	52	3950	535	5.74	0.016	0.15	1220	<d.l.	0.01	<d.l.	1.9	2.9	<d.l.	0.2	<d.l.	0.06	10.6	0.7	1785	<d.l.
		yellowish brown serpentinite	04SFFPG01 CR02	<d.l.	24	4220	553	5.52	0.007	0.17	1535	<d.l.	0.02	<d.l.	0.8	3.7	<d.l.	0.1	<d.l.	<d.l.	4.6	0.2	1245	<d.l.
	04SFFPG03	white alteration vein and serpentinite	04SFFPG03 CR01	<d.l.	46	3840	730	4.81	0.009	0.13	1145	<d.l.	0.01	<d.l.	0.6	4.5	0.1	0.2	<d.l.	<d.l.	7.6	0.4	1980	<d.l.
		conglomerate with reddish brown precipitates	04SFFPG03 CR02	0.031	76	4300	3830	6.6	0.014	0.14	1275	0.01	0.02	0.3	0.7	24.9	0.5	2.3	0.05	<d.l.	40.2	0.5	674	<d.l.
		bluish gray clayey materials	04SFFPG03 CR03	<d.l.	42	3810	460	4.72	0.006	0.12	1015	0.01	0.01	<d.l.	0.5	3.3	<d.l.	0.1	<d.l.	<d.l.	7	0.3	2070	<d.l.
		Dupricate	04SFFPG03 CR01	<d.l.	49	3220	956	4.72	0.009	0.13	1070	0.01	0.01	<d.l.	0.6	2.9	<d.l.	0.2	<d.l.	<d.l.	7.3	0.2	2450	<d.l.

Area	Sampling No.	Lithology	Sample No.	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y	Os	Ir	Ru	Rh	Pt	Pd	Au	Ag
				ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppm
Central Hill	04SFFPG01	black serpentinite	04SFFPG01 CR01	0.6	0.7	<d.l.	<d.l.	0.1	<d.l.	0.1	<d.l.	0.1	<d.l.	<d.l.	<d.l.	0.1	<d.l.	1.2	<d.l.	<d.l.	<d.l.	1	12	4	<d.l.	<1
		yellowish brown serpentinite	04SFFPG01 CR02	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	0.6	<d.l.	<d.l.	<d.l.	1	14	4	<d.l.	<1
	04SFFPG03	white alteration vein and serpentinite	04SFFPG03 CR01	1.3	1.2	0.1	0.6	0.1	0.1	0.2	<d.l.	0.1	<d.l.	0.1	<d.l.	0.1	<d.l.	1.8	<d.l.	<d.l.	<d.l.	<d.l.	9	4	<d.l.	<1
		conglomerate with reddish brown precipitates	04SFFPG03 CR02	5.3	10.6	0.9	3.9	0.9	0.2	0.9	0.1	1	0.2	0.7	0.1	0.6	0.1	5.1	<d.l.	<d.l.	<d.l.	2	24	6	<d.l.	<1
		bluish gray clayey materials	04SFFPG03 CR03	0.5	0.5	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	<d.l.	0.8	<d.l.	<d.l.	<d.l.	<d.l.	7	3	<d.l.	<1
		Dupricate	04SFFPG03 CR01	0.7	0.6	0.1	<d.l.	0.1	<d.l.	0.1	<d.l.	0.1	<d.l.	0.1	<d.l.	0.1	<d.l.	1.5	<d.l.	<d.l.	<d.l.	1	8	3	<d.l.	<1

Area	Sampling No.	Lithology	Sample No.	Li	Be	Mo	W	Re	Cd	Hg	Ga	In	Tl	Ge	Sn	P	As	Sb	Bi	S	Se	Te
				ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	%	ppm	%	ppm	ppm
Central Hill	04SFFPG01	black serpentinite	04SFFPG01 CR01	1.7	<d.l.	7.97	<d.l.	0.003	<d.l.	<d.l.	0.74	<d.l.	0.35	0.13	0.2	90	<d.l.	<d.l.	0.03	2.85	1	0.06
		yellowish brown serpentinite	04SFFPG01 CR02	0.5	<d.l.	2.1	0.1	<d.l.	<d.l.	<d.l.	0.55	<d.l.	<d.l.	0.12	0.3	170	<d.l.	<d.l.	0.13	0.05	1	0.06
	04SFFPG03	white alteration vein and serpentinite	04SFFPG03 CR01	1.6	<d.l.	1.1	0.3	<d.l.	<d.l.	<d.l.	0.8	<d.l.	0.15	0.11	<d.l.	170	<d.l.	<d.l.	0.01	0.33	1	0.06
		conglomerate with reddish brown precipitates	04SFFPG03 CR02	2.2	0.18	4.71	1	<d.l.	<d.l.	<d.l.	1.68	0.012	1.22	0.12	0.2	390	<d.l.	<d.l.	0.21	0.03	1	0.9
		bluish gray clayey materials	04SFFPG03 CR03	2.3	<d.l.	1	0.1	<d.l.	<d.l.	<d.l.	0.95	<d.l.	0.05	0.11	<d.l.	120	<d.l.	<d.l.	<d.l.	2.1	1	0.05
		Dupricate	04SFFPG03 CR01	1.2	<d.l.	0.92	0.3	<d.l.	<d.l.	<d.l.	0.67	<d.l.	0.16	0.1	<d.l.	200	<d.l.	<d.l.	<d.l.	0.39	1	<d.l.

Table 4 Statistical Values

Statistical Values	SiO_2	TiO_2	Al_2O_3	FeO	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^+	H_2O^-	C	LOI	Ti	V
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	ppm
No. of Samples	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Maximum	34.30	0.06	0.70	3.55	8.20	0.50	35.40	11.25	0.09	0.03	0.10	12.05	0.52	2.48	18.55	0.031	76
Minimum	31.10	0.01	0.28	0.51	3.54	0.04	31.20	3.75	0.02	0.01	0.01	9.94	0.20	0.82	15.35	0.00	24
Average	32.54	0.02	0.40	2.04	5.33	0.15	33.04	8.53	0.07	0.02	0.04	10.67	0.35	1.88	16.65	0.01	48
Standard Deviation	1.38	0.02	0.17	1.22	2.01	0.20	1.56	3.09	0.03	0.01	0.04	0.96	0.12	0.68	1.34	0.01	19
Coeficient of Variation	0.043	1.118	0.439	0.596	0.376	1.313	0.047	0.362	0.409	0.354	0.991	0.090	0.350	0.360	0.080	1.55	0.392

Statistical Values	Cr	Mn	Fe	Co	Ni	Cu	Zn	Th	U	Zr	Hf	Nb	Ta	Cs	Ba	Rb	Sr
	ppm	ppm	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
No. of Samples	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Maximum	4300	3830	6.60	0.016	1535	0.01	0.02	0.3	1.9	24.9	0.50	2.3	0.050	0.060	40	0.7	2070
Minimum	3810	460	4.72	0.006	1015	0.01	0.01	0.1	0.5	2.9	0.05	0.1	0.025	0.025	5	0.2	674
Average	4024	1222	5.48	0.010	1238	0.01	0.01	0.1	0.9	7.9	0.15	0.6	0.030	0.032	14	0.4	1551
Standard Deviation	223	1461	0.77	0.004	193	0.00	0.01	0.1	0.6	9.5	0.20	1.0	0.011	0.016	15	0.2	585
Coeficient of Variation	0.056	1.196	0.140	0.422	0.156	0.391	0.391	0.639	0.633	1.214	1.312	1.660	0.373	0.489	1.057	0.458	0.378

Statistical Values	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y	Rh
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb
No. of Samples	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Maximum	5.3	10.6	0.90	3.90	0.90	0.20	0.90	0.10	1.00	0.20	0.70	0.10	0.60	0.10	5.1	2.0
Minimum	0.3	0.3	0.05	0.25	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.6	0.5
Average	1.6	2.7	0.23	1.05	0.24	0.09	0.26	0.06	0.26	0.08	0.19	0.06	0.18	0.06	1.9	1.0
Standard Deviation	2.1	4.5	0.38	1.60	0.37	0.07	0.36	0.02	0.41	0.07	0.29	0.02	0.24	0.02	1.8	0.6
Coeficient of Variation	1.327	1.682	1.631	1.524	1.541	0.724	1.396	0.373	1.594	0.839	1.505	0.373	1.312	0.373	0.972	0.612

Statistical Values	Pt	Pd	Li	Be	Mo	W	Re	Ga	In	Tl	Ge	Sn	P	Bi	S	Te
	ppb	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm
No. of Samples	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Maximum	24	6	2.3	0.180	7.97	1.0	0.003	1.68	0.012	1.22	0.13	0.3	390	0.210	2.85	0.90
Minimum	7	3	0.5	0.025	1.00	0.1	0.001	0.55	0.003	0.01	0.11	0.1	90	0.005	0.03	0.05
Average	13	4	1.7	0.056	3.38	0.3	0.001	0.94	0.004	0.36	0.12	0.2	188	0.077	1.07	0.23
Standard Deviation	7	1	0.7	0.069	2.97	0.4	0.001	0.44	0.004	0.50	0.01	0.1	118	0.090	1.31	0.38
Coeficient of Variation	0.501	0.261	0.431	1.238	0.880	1.282	0.639	0.462	0.966	1.406	0.071	0.465	0.628	1.168	1.225	1.667

Table 5 Correlation Coefficient

simple correlation coefficient	SiO2	TiO2	Al2O3	FeO	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	H2O-	H2O+	CO2	LOI
SiO2	1.0000														
TiO2	0.7113	1.0000													
Al2O3	0.5929	0.9766	1.0000												
FeO	-0.7362	-0.7038	-0.6798	1.0000											
Fe2O3	0.8908	0.8000	0.7368	-0.9589	1.0000										
MnO	0.6625	0.9933	0.9686	-0.7015	0.7826	1.0000									
MgO	0.8948	0.8458	0.7726	-0.5583	0.7540	0.7876	1.0000								
CaO	-0.9678	-0.8647	-0.7750	0.7853	-0.9264	-0.8266	-0.9396	1.0000							
Na2O	-0.2154	0.4966	0.5700	0.1113	-0.0882	0.5402	0.1530	-0.0179	1.0000						
K2O	0.8180	0.7906	0.6502	-0.6973	0.8226	0.8077	0.7253	-0.8588	0.1309	1.0000					
P2O5	0.4884	0.9603	0.9731	-0.5827	0.6421	0.9742	0.6909	-0.6908	0.7039	0.6748	1.0000				
H2O-	0.9003	0.7885	0.6428	-0.5538	0.7579	0.7681	0.8930	-0.9163	0.1032	0.9278	0.6328	1.0000			
H2O+	0.9259	0.8061	0.7608	-0.8784	0.9576	0.7585	0.8645	-0.9552	-0.0928	0.7204	0.6279	0.7584	1.0000		
CO2	-0.9607	-0.8774	-0.7855	0.7603	-0.9102	-0.8405	-0.9497	0.9986	-0.0569	-0.8674	-0.7100	-0.9307	-0.9408	1.0000	
LOI	-0.4358	-0.5441	-0.5067	-0.0920	-0.1529	-0.4832	-0.7590	0.4996	-0.4330	-0.3044	-0.4951	-0.5979	-0.3476	0.5330	1.0000
Ti	0.7113	1.0000	0.9766	-0.7038	0.8000	0.9933	0.8458	-0.8647	0.4966	0.7906	0.9603	0.7885	0.8061	-0.8774	-0.5441
V	0.3247	0.8319	0.8094	-0.2651	0.3787	0.8621	0.5861	-0.5204	0.8360	0.6389	0.9130	0.6255	0.3532	-0.5569	-0.6039
Cr	0.9943	0.6905	0.5856	-0.7751	0.9089	0.6379	0.8724	-0.9585	-0.2658	0.7753	0.4625	0.8509	0.9482	-0.9464	-0.3803
Mn	0.7054	0.9977	0.9696	-0.7237	0.8113	0.9978	0.8209	-0.8593	0.4937	0.8152	0.9616	0.7895	0.7977	-0.8715	-0.4981
Fe	0.8983	0.8183	0.6927	-0.5194	0.7357	0.7844	0.9494	-0.9267	0.1540	0.8672	0.6658	0.9864	0.7804	-0.9430	-0.7048
Co	0.3835	0.4581	0.3100	0.0821	0.1505	0.4738	0.5188	-0.4192	0.4170	0.6438	0.4360	0.7345	0.1332	-0.4612	-0.6604
Ni	0.7617	0.1074	-0.0339	-0.5169	0.6046	0.0583	0.4345	-0.5837	-0.7853	0.4774	-0.1648	0.5263	0.6030	-0.5561	0.0362
Cu	0.1056	0.6124	0.7554	-0.2491	0.2444	0.5793	0.4448	-0.3033	0.6420	0.0000	0.6970	0.0898	0.3863	-0.3130	-0.4955
Zn	0.9306	0.6124	0.5456	-0.8492	0.9198	0.5561	0.7667	-0.8902	-0.3717	0.6455	0.3858	0.6887	0.9587	-0.8662	-0.2051
Th	0.7113	1.0000	0.9766	-0.7038	0.8000	0.9933	0.8458	-0.8647	0.4966	0.7906	0.9603	0.7885	0.8061	-0.8774	-0.5441
U	0.0698	-0.1961	-0.3478	0.5672	-0.3378	-0.2093	0.1265	0.0379	-0.0487	0.1240	-0.2571	0.3201	-0.2878	0.0052	-0.4827
Zr	0.7039	0.9981	0.9759	-0.7345	0.8167	0.9963	0.8203	-0.8591	0.4879	0.8002	0.9617	0.7754	0.8075	-0.8700	-0.4915
Hf	0.6749	0.9939	0.9707	-0.7254	0.8015	0.9994	0.7898	-0.8362	0.5171	0.8082	0.9696	0.7655	0.7770	-0.8484	-0.4659
Nb	0.7010	0.9987	0.9693	-0.6394	0.7884	0.9966	0.8347	-0.8559	0.5151	0.8079	0.9643	0.7981	0.7847	-0.8703	-0.5414
Ta	0.7113	1.0000	0.9766	-0.7038	0.8000	0.9933	0.8458	-0.8647	0.4966	0.7906	0.9603	0.7885	0.8061	-0.8774	-0.5441
Cs	-0.0970	-0.2500	-0.3727	0.6928	-0.4816	-0.2554	0.0215	0.1763	0.0828	0.0000	-0.2591	0.1925	-0.4264	0.1388	-0.4813
Ba	0.6636	0.9895	0.9571	-0.6072	0.7238	0.9887	0.8321	-0.8242	0.5776	0.7930	0.9685	0.8014	0.7281	-0.8440	-0.6050
Rb	0.0338	0.2325	0.1225	0.3832	-0.1853	0.2639	0.2383	-0.0878	0.5484	0.3676	0.2941	0.4498	-0.2037	-0.1368	-0.5839
Sr	-0.9758	-0.8372	-0.7492	0.8152	-0.9441	-0.7972	-0.9200	0.9970	0.0466	-0.8431	-0.6529	-0.8929	-0.9702	0.9916	0.4457
La	0.6207	0.9828	0.9605	-0.6922	0.7618	0.9975	0.7441	-0.7926	0.5713	0.8042	0.9791	0.7426	0.7212	-0.8073	-0.4444
Ce	0.6757	0.9969	0.9726	-0.6944	0.7826	0.9992	0.8088	-0.8374	0.5345	0.8010	0.9725	0.7763	0.7699	-0.8516	-0.5125
Pr	0.6933	0.9983	0.9750	-0.7162	0.8020	0.9980	0.8177	-0.8511	0.5081	0.8010	0.9666	0.7776	0.7921	-0.8635	-0.5039
Nd	0.6805	0.9955	0.9722	-0.7229	0.8019	0.9992	0.7982	-0.8408	0.5146	0.8063	0.9690	0.7693	0.7817	-0.8531	-0.4772
Sm	0.6975	0.9977	0.9666	-0.6847	0.7845	0.9970	0.8309	-0.8528	0.5204	0.8127	0.9650	0.8005	0.7778	-0.8677	-0.5404
Eu	0.5739	0.9432	0.9212	-0.7418	0.7737	0.9734	0.6441	-0.7455	0.5393	0.8135	0.9515	0.6387	0.6872	-0.7561	-0.2871
Gd	0.6538	0.9857	0.9547	-0.7039	0.7815	0.9993	0.7652	-0.8170	0.5404	0.8279	0.9700	0.7715	0.7413	-0.8312	-0.4525
Tb	0.7113	1.0000	0.9766	-0.7038	0.8000	0.9933	0.8458	-0.8647	0.4966	0.7906	0.9603	0.7885	0.8061	-0.8774	-0.5441
Dy	0.6991	0.9982	0.9679	-0.6869	0.7864	0.9968	0.8327	-0.8542	0.5180	0.8105	0.9647	0.7994	0.7810	-0.8689	-0.5409
Ho	0.7113	1.0000	0.9766	-0.7038	0.8000	0.9933	0.8458	-0.8647	0.4966	0.7906	0.9603	0.7885	0.8061	-0.8774	-0.5441
Er	0.6872	0.9971	0.9738	-0.7196	0.8021	0.9988	0.8083	-0.8462	0.5113	0.8038	0.9680	0.7737	0.7871	-0.8586	-0.4910
Tm	0.7113	1.0000	0.9766	-0.7038	0.8000	0.9933	0.8458	-0.8647	0.4966	0.7906	0.9603	0.7885	0.8061	-0.8774	-0.5441
Yb	0.6882	0.9944	0.9589	-0.6724	0.7741	0.9971	0.8207	-0.8442	0.5330	0.8236	0.9657	0.8058	0.7601	-0.8603	-0.5371
Lu	0.7113	1.0000	0.9766	-0.7038	0.8000	0.9933	0.8458	-0.8647	0.4966	0.7906	0.9603	0.7885	0.8061	-0.8774	-0.5441
Y	0.5990	0.9687	0.9367	-0.6620	0.7357	0.9904	0.7187	-0.7706	0.5913	0.8233	0.9727	0.7505	0.6799	-0.7877	-0.4349
Rh	0.9003	0.9129	0.8211	-0.6408	0.8197	0.8808	0.9694	-0.9652	0.2266	0.8660	0.7792	0.9541	0.8617	-0.9774	-0.6648
Pt	0.9258	0.9133	0.8180	-0.7413	0.8923	0.8889	0.9349	-0.9847	0.1596	0.9092	0.7713	0.9496	0.9010	-0.9911	-0.5423
Pd	0.8184	0.9186	0.8184	-0.7374	0.8576	0.9269	0.8135	-0.9074	0.2872	0.9682	0.8276	0.9208	0.7941	-0.9181	-0.4186
Li	-0.2882	0.4215	0.5320	0.1848	-0.1734	0.4465	0.1226	0.0576	0.9715	-0.0494	0.6320	-0.0269	-0.1229	0.0219	-0.4626
Be	0.7113	1.0000	0.9766	-0.7038	0.8000	0.9933	0.8458	-0.8647	0.4966	0.7906	0.9603	0.7885	0.8061	-0.8774	-0.5441
Mo	0.3593	0.2509	0.0996	0.2772	-0.0066	0.2328	0.5002	-0.3288	0.2077	0.4413	0.1820	0.6458	0.0575	-0.3681	-0.7481
W	0.6221	0.9704	0.9549	-0.7632	0.8047	0.9882	0.7068	-0.7908	0.5168	0.8005	0.9629	0.7071	0.7469	-0.8000	-0.3449
Re	-0.0970	-0.2500	-0.3727	0.6928	-0.4816	-0.2554	0.0215	0.1763	0.0828	*	-0.2591	0.1925	-0.4264	0.1388	-0.4813
Ga	0.4490	0.9443	0.9763	-0.5307	0.5914	0.9493	0.6924	-0.6581	0.7323	0.5924	0.9921	0.5818	0.6087	-0.6779	-0.5467
In	0.7113	1.0000	0.9766	-0.7038	0.8000	0.9933	0.8458	-0.8647	0.4966	0.7906	0.9603	0.7885	0.8061	-0.8774	-0.5441
Tl	0.6611	0.9649	0.9101	-0.5426	0.6826	0.9683	0.8276	-0.8109	0.5826	0.8264	0.9422	0.8419	0.6781	-0.8351	-0.6372
Ge	0.5055	0.1336	-0.0412	0.1847	0.0873	0.0910	0.5249	-0.3943	-0.1548	0.4226	-0.0244	0.6567	0.1717	-0.4187	-0.6488
Sn	0.7864	0.1336	-0.0069	-0.3654	0.5192	0.0607	0.5632	-0.6091	-0.7078	0.4226	-0.1467	0.5832	0.5964	-0.5909	-0.2349
P	0.7329	0.9571	0.9371	-0.8726	0.9081	0.9596	0.7559	-0.8680	0.3341	0.8091	0.8996	0.7277	0.8647	-0.8674	-0.2959
Bi	0.9675	0.8264	0.7511	-0.8413	0.9546	0.7829	0.9060	-0.9889	-0.0730	0.8056	0.6406	0.8527	0.9868	-0.9801	-0.4125
S	-0.5476	-0.4435	-0.4211	0.9388	-0.8279	-0.4619	-0.2583	0.5584	0.2856	-0.5573	-0.3353	-0.3295	-0.6841	0.5240	-0.4233
Te	0.7161	0.9999	0.9743	-0.7064	0.8035	0.9936	0.8468	-0.8679	0.4916	0.7976	0.9586	0.7942	0.8076	-0.8806	-0.5417

simple correlation coefficient	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Th	U	Zr	Hf	Nb	Ta	Cs	Ba	Rb	Sr
Ti	1.0000																		
V	0.8319	1.0000																	
Cr	0.6905	0.2605	1.0000																
Mn	0.9977	0.9354	0.6837	1.0000															
Fe	0.8183	0.6473	0.8519	0.8088	1.0000														
Co	0.4581	0.7077	0.2832	0.4617	0.7152	1.0000													
Ni	0.1074	-0.3202	0.7821	0.1118	0.4751	0.0396	1.0000												
Cu	0.6124	0.5337	0.1266	0.5768	0.2168	-0.0831	-0.4409	1.0000											
Zn	0.6124	0.0970	0.9641	0.6058	0.6931	0.0208	0.7918	0.1667	1.0000										
Th	1.0000	0.8319	0.6905	0.9977	0.8183	0.4581	0.1074	0.6124	0.6124	1.0000									
U	-0.1961	0.0886	-0.0157	-0.2068	0.3072	0.7397	0.1412	-0.4804	-0.2402	-0.1961	1.0000								
Zr	0.9981	0.8231	0.6856	0.9994	0.7978	0.4322	0.1107	0.5968	0.6160	0.9981	-0.2353	1.0000							
Hf	0.9939	0.8437	0.6526	0.9986	0.7812	0.4481	0.0792	0.5797	0.5797	0.9939	-0.2339	0.9980	1.0000						
Nb	0.9987	0.8529	0.6756	0.9986	0.8224	0.4929	0.0948	0.5878	0.5878	0.9987	-0.1685	0.9973	0.9959	1.0000					
Ta	1.0000	0.8319	0.6905	0.9977	0.8183	0.4581	0.1074	0.6124	0.6124	1.0000	-0.1961	0.9981	0.9939	0.9987	1.0000				
Cs	-0.2500	0.1188	-0.1851	-0.2626	0.1911	0.7126	-0.0523	-0.4082	-0.4082	-0.2500	0.9806	-0.2905	-0.2840	-0.2206	-0.2500	1.0000			
Ba	0.9895	0.8981	0.5286	0.9874	0.8306	0.5652	0.0347	0.5921	0.5181	0.9895	-0.0883	0.9837	0.9842	0.9940	0.9895	-0.1284	1.0000		
Rb	0.2325	0.6493	-0.0721	0.2354	0.4378	0.9349	-0.2619	-0.0949	-0.3322	0.2325	0.7751	0.2048	0.2311	0.2727	0.2325	0.8137	0.3670	1.0000	
Sr	-0.8372	-0.4596	-0.9734	-0.8327	-0.9000	-0.3587	-0.6281	-0.2788	-0.9220	-0.8372	0.0777	-0.8340	-0.8094	-0.8261	-0.8372	0.2236	-0.7869	-0.0182	1.0000
La	0.9828	0.8765	0.5945	0.9910	0.7522	0.4738	0.0167	0.5667	0.5126	0.9828	-0.2234	0.9887	0.9960	0.9886	0.9828	-0.2623	0.9817	0.2778	-0.7620
Ce	0.9969	0.8590	0.6513	0.9968	0.7980	0.4768	0.0672	0.5939	0.5683	0.9969	-0.1972	0.9977	0.9985	0.9989	0.9969	-0.2445	0.9920	0.2639	-0.8077
Pr	0.9983	0.8394	0.6722	0.9997	0.8001	0.4535	0.0928	0.5961	0.5961	0.9983	-0.2162	0.9996	0.9986	0.9987	0.9983	-0.2682	0.9882	0.2321	-0.8239
Nd	0.9955	0.8427	0.6592	0.9992	0.7870	0.4498	0.0832	0.5847	0.5847	0.9955	-0.2288	0.9987	0.9999	0.9970	0.9955	-0.2794	0.9856	0.2315	-0.8139
Sm	0.9977	0.8588	0.6708	0.9983	0.8233	0.5032	0.0909	0.5801	0.5801	0.9977	-0.1601	0.9965	0.9960	0.9999	0.9977	-0.2116	0.9948	0.2847	-0.8223
Eu	0.9432	0.8357	0.5526	0.9621	0.6749	0.4103	0.0179	0.4901	0.4901	0.9432	-0.3027	0.9595	0.9740	0.9519	0.9432	-0.3430	0.9353	0.2193	-0.7209
Gd	0.9857	0.8676	0.6266	0.9939	0.7787	0.4907	0.0594	0.5407	0.5407	0.9857	-0.1993	0.9910	0.9972	0.9915	0.9857	-0.2464	0.9837	0.2829	-0.7873
Tb	1.0000	0.8319	0.6905	0.9977	0.8183	0.4581	0.1074	0.6124	0.6124	1.0000	-0.1961	0.9981	0.9939	0.9987	1.0000	-0.2500	0.9895	0.2325	-0.8372
Dy	0.9982	0.8561	0.6730	0.9985	0.8229	0.4994	0.0927	0.5837	0.5837	0.9982	-0.1640	0.9969	0.9960	1.0000	0.9982	-0.2158	0.9944	0.2791	-0.8241
Ho	1.0000	0.8319	0.6905	0.9977	0.8183	0.4581	0.1074	0.6124	0.6124	1.0000	-0.1961	0.9981	0.9939	0.9987	1.0000	-0.2500	0.9895	0.2325	-0.8372
Er	0.9971	0.8411	0.6660	0.9996	0.7938	0.4518	0.0881	0.5907	0.5907	0.9971	-0.2224	0.9993	0.9994	0.9981	0.9971	-0.2737	0.9871	0.2318	-0.8192
Tm	1.0000	0.8319	0.6905	0.9977	0.8183	0.4581	0.1074	0.6124	0.6124	1.0000	-0.1961	0.9981	0.9939	0.9987	1.0000	-0.2500	0.9895	0.2325	-0.8372
Yb	0.9944	0.8723	0.6582	0.9967	0.8244	0.5278	0.0814	0.5606	0.5606	0.9944	-0.1393	0.9936	0.9951	0.9965	0.9944	-0.1894	0.9958	0.3138	-0.8122
Lu	1.0000	0.8319	0.6905	0.9977	0.8183	0.4581	0.1074	0.6124	0.6124	1.0000	-0.1961	0.9981	0.9939	0.9987	1.0000	-0.2500	0.9895	0.2325	-0.8372
Y	0.9687	0.8990	0.5659	0.9804	0.7512	0.5239	-0.0004	0.5191	0.4696	0.9687	-0.1757	0.9754	0.9869	0.9787	0.9687	-0.2119	0.9767	0.3376	-0.7368
Rh	0.9129	0.6943	0.8678	0.9037	0.9773	0.6040	0.4135	0.3727	0.7454	0.9129	0.1074	0.8983	0.8814	0.9116	0.9129	*	0.9074	0.3184	-0.9421
Pt	0.9133	0.6512	0.9014	0.9120	0.9543	0.5399	0.4777	0.3176	0.8009	0.9133	0.0199	0.9076	0.8933	0.9121	0.9133	-0.1015	0.8938	0.2320	-0.9701
Pd	0.9186	0.7520	0.7823	0.9335	0.8938	0.6026	0.3520	0.2500	0.6667	0.9186	0.0000	0.9240	0.9275	0.9292	0.9186	-0.1021	0.9159	0.3322	-0.8860
Li	0.4215	0.7309	-0.3237	0.4067	0.0556	0.5239	-0.8383	0.7520	-0.3951	0.4215	-0.1163	0.4064	0.4256	0.4300	0.4215	0.0312	0.4910	0.4246	0.1176
Be	1.0000	0.8319	0.6905	0.9977	0.8183	0.4581	0.1074	0.6124	0.6124	1.0000	-0.1961	0.9981	0.9939	0.9987	1.0000	-0.2500	0.9895	0.2325	-0.8372
Mo	0.2509	0.4701	0.2655	0.2364	0.6549	0.9287	0.1438	-0.1600	0.0089	0.2509	0.8982	0.2092	0.2079	0.2766	0.2509	0.8640	0.3553	0.8765	-0.2750
W	0.9704	0.8223	0.6060	0.9827	0.7082	0.3837	0.0510	0.5512	0.5512	0.9704	-0.3199	0.9827	0.9905	0.9740	0.9704	-0.3657	0.9548	0.1766	-0.7681
Re	-0.2500	0.1188	-0.1851	-0.2626	0.1911	0.7126	-0.0523	-0.4082	-0.4082	-0.2500	0.9806	-0.2905	-0.2840	-0.2206	-0.2500	1.0000	-0.1284	0.8137	0.2236
Ga	0.9443	0.8997	0.4268	0.9381	0.6344	0.3947	-0.2207	0.7773	0.3583	0.9443	-0.2728	0.9408	0.9444	0.9442	0.9443	-0.2617	0.9521	0.2703	-0.6188
In	1.0000	0.8319	0.6905	0.9977	0.8183	0.4581	0.1074	0.6124	0.6124	1.0000	-0.1961	0.9981	0.9939	0.9987	1.0000	-0.2500	0.9895	0.2325	-0.8372
Tl	0.9649	0.9216	0.6135	0.9648	0.8619	0.6694	0.0433	0.5088	0.4723	0.9649	0.0350	0.9565	0.9503	0.9750	0.9649	-0.0067	0.9910	0.4788	-0.7662
Ge	0.1336	0.1906	0.4333	0.1158	0.6580	0.7754	0.4625	-0.3273	0.2182	0.1336	0.8910	0.0927	0.0759	0.1490	0.1336	0.8018	0.2019	0.6524	-0.3645
Sn	0.1336	-0.2541	0.7943	0.1195	0.5723	0.1632	0.9513	-0.3273	0.7638	0.1336	0.3145	0.1177	0.0759	0.1179	0.1336	0.1336	0.0808	-0.1243	-0.6401
P	0.9571	0.6915	0.7334	0.9668	0.7292	0.2720	0.2281	0.5184	0.7118	0.9571	-0.3866	0.9710	0.9688	0.9525	0.9571	-0.4643	0.9142	0.0132	-0.8600
Bi	0.8264	0.4179	0.9738	0.8204	0.8645	0.2821	0.6320	0.3095	0.9436	0.8264	-0.1462	0.8246	0.7975	0.8115	0.8264	-0.2920	0.7657	-0.0607	-0.9966
S	-0.4435	-0.0225	-0.5989	-0.4785	-0.2557	0.2685	-0.5283	-0.0049	-0.7173	-0.4435	0.6344	-0.4690	-0.4893	-0.4328	-0.4435	0.7568	-0.3368	0.5253	0.6041
Te	0.9999	0.8315	0.6947	0.9981	0.8224	0.4633	0.1148	0.6032	0.6154	0.9999	-0.1909	0.9982	0.9943	0.9999	0.9999	-0.2463	0.9897	0.2359	-0.9406

*correlation coefficient = 0

Table 5 Correlation Coefficient

simple correlation coefficient	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y	Rh	Pt	Pd	Li	Be	Mo	W	Re	Ga	In	Tl	Ge	Sn	P	Bi	S	Te
SiO_2																																
TiO_2																																
Al_2O_3																																
FeO																																
Fe_2O_3																																
MnO																																
MgO																																
CaO																																
Na_2O																																
K_2O																																
P_2O_5																																
H_2O+																																
CO_2																																
LOI																																
V																																
Cr																																
Mn																																
Fe																																
Co																																
Ni																																
Cu																																
Zn																																
Th																																
U																																
Zr																																
Hf																																
Nb																																
Ta																																
Cs																																
Ba																																
Rb																																
Sr																																
La	1.0000																															
Ce	0.9941	1.0000																														
Pr	0.9912	0.9993	1.0000																													
Nd	0.9949	0.9990	0.9993	1.0000																												
Sm	0.9898	0.9990	0.9963	0.9969	1.0000																											
Eu	0.9850	0.9635	0.9608	0.9705	0.9540	1.0000																										
Gd	0.9989	0.9954	0.9932	0.9963	0.9927	0.9825	1.0000																									
Tb	0.9826	0.9969	0.9983	0.9955	0.9977	0.9432	0.9857	1.0000																								
Dy	0.9992	0.9990	0.9985	0.9970	1.0000	0.9531	0.9922	0.9982	1.0000																							
Ho	0.9828	0.9969	0.9983	0.9955	0.9977	0.9432	0.9857	1.0000	0.9982	1.0000																						
Er	0.9932	0.9993	0.9998	0.9998	0.9978	0.9657	0.9949	0.9971	0.9980	0.9971	1.0000																					
Tm	0.9828	0.9969	0.9983	0.9955	0.9977	0.9432	0.9857	1.0000	0.9982	1.0000	0.9971	1.0000																				
Yb	0.9917	0.9982	0.9962	0.9957	0.9993	0.9592	0.9947	0.9944	0.9990	0.9944	0.9962	0.9944	1.0000																			
Lu	0.9828	0.9969	0.9983	0.9955	0.9977	0.9432	0.9857	1.0000	0.9982	1.0000	0.9971	1.0000	0.9944	1.0000																		
Y	0.9967	0.9850	0.9797	0.9851	0.9811	0.9864	0.9959	0.9687	0.9800	0.9687	0.9825	0.9687	0.9862	0.9687	1.0000																	
Rh	0.8512	0.8929	0.8977	0.8864	0.9108	0.7828	0.8717	0.9129	0.9112	0.9129	0.8924	0.9129	0.9077	0.9129	0.8401	1.0000																
Pt	0.8631	0.8967	0.9042	0.8968	0.9112	0.8179	0.8846	0.9133	0.9116	0.9133	0.9007	0.9133	0.9082	0.9133	0.8520	0.9881	1.0000															
Pd	0.9203	0.9241	0.9246	0.9269	0.9319	0.9102	0.9368	0.9186	0.9307	0.9186	0.9259	0.9186	0.9376	0.9186	0.9269	0.9317	0.9597	1.0000														
Li	0.4694	0.4471	0.4243	0.4253	0.4323	0.4176	0.4347	0.4215	0.4312	0.4215	0.4248	0.4215	0.4376	0.4215	0.4744	0.1425	0.0602	0.1402	1.0000													
Be	0.9628	0.9969	0.9983	0.9956	0.9977	0.9432	0.9857	1.0000	0.9982	1.0000	0.9971	1.0000	0.9944	1.0000	0.9687	0.9129	0.9133	0.9186	0.4215	1.0000												
Mo	0.2137	0.2475	0.2287	0.2140	0.2843	0.1113	0.2369	0.2509	0.2807	0.2509	0.2216	0.2509	0.3026	0.2509	0.2529	0.5027	0.4092	0.3873	0.1175	0.2509	1.0000											
W	0.9926	0.9823	0.9824	0.9884	0.9745	0.9937	0.9911	0.9704	0.9743	0.9704	0.9855	0.9704	0.9749	0.9704	0.9860	0.8216	0.8506	0.9129	0.4145	0.9704	0.1091	1.0000										
Re	-0.2623	-0.2445	-0.2682	-0.2794	-0.2116	-0.3430	-0.2464	-0.2500	-0.2158	-0.2500	-0.2737	-0.2500	-0.1894	-0.2500	-0.2119	*	-0.1015	-0.1021	0.0312	-0.2500	0.8640	-0.3657	1.0000									
Ga	0.9505	0.9513	0.9458	0.9451	0.9437	0.9083	0.9387	0.9443	0.9440	0.9443	0.9456	0.9443	0.9414	0.9443	0.9378	0.7543	0.7331	0.7679	0.6880	0.9443	0.1662	0.9294	-0.2617	1.0000								
In	0.9828	0.9969	0.9983	0.9955	0.9977	0.9432	0.9857	1.0000	0.9982	1.0000	0.9971	1.0000	0.9944	1.0000	0.9687	0.9129	0.9133	0.9186	0.4215	1.0000	0.2509	0.9704	-0.2500	0.9443	1.0000							
Tl	0.9628	0.9710	0.9639	0.9616	0.9775	0.9139	0.9675	0.9649	0.9764	0.9649	0.9630	0.9649	0.9827	0.9649	0.9671	0.9134	0.8933	0.9273	0.4771	0.9649	0.4642	0.9256	-0.0067	0.9185	0.9649	1.0000						
Ge	0.0552	0.1106	0.1035	0.0840	0.1535	-0.0458	0.0906	0.1336	0.1514	0.1336	0.0941	0.1336	0.1645	0.1336	0.0809	0.4880	0.4159	0.3273	-0.2253	0.1336	0.9295	-0.0301	0.8018	-0.0453	0.1336	0.3020	1.0000					
Sn	0.0057	0.0804	0.1035	0.0840	0.1131	-0.0458	0.0494	0.1336	0.1154	0.1336	0.0941	0.1336	0.1012	0.1336	-0.0162	0.4880	0.5063	0.3273	-0.7259	0.1336	0.3394	0.0075	0.1336	-0.1756	0.1336	0.0991	0.6429	1.0000				
P	0.9538	0.9566	0.9647	0.9679	0.9506	0.9556	0.9580	0.9571	0.9515	0.9571	0.9664	0.9571	0.9450	0.9571	0.9352	0.8478	0.8917	0.9130	0.2473	0.9571	0.0319	0.9761	-0.4643	0.8654	0.9571	0.8714	-0.0304	0.1722	1.0000			
Bi	0.7464	0.7939	0.8125	0.8021	0.8066	0.7075	0.7705	0.8264	0.8089	0.8264	0.8076	0.8264	0.7938	0.8264	0.7155	0.9188	0.9512	0.8573	-0.1304	0.8264	0.2033	0.7595	-0.2920	0.6110	0.8264	0.7365	0.3055	0.6377	0.8624	1.0000		
S	-0.4657	-0.4455	-0.4682	-0.4833	-0.4293	-0.5647	-0.4763	-0.4435	-0.4309	-0.4435	-0.4756	-0.4435	-0.4203	-0.4435	-0.4440	-0.3684	-0.5028	-0.5408	0.3711	-0.4435	0.4694	-0.5628	0.7568	-0.2682	-0.4435	-0.2734	0.3395	-0.2976	-0.6823	-0.6360	1.0000	
Te	0.9833	0.9971	0.9985	0.9958	0.9981	0.9445	0.9865	0.9999	0.9985	0.9999	0.9974	0.9999	0.9950	0.9999	0.9697	0.9155	0.9167	0.9230	0.4143	0.9999	0.2554	0.9710	-0.2463	0.9414	0.9999	0.9660	0.1396	0.1396	0.9580	0.8292	-0.4474	1.0000

* correlation coefficient = 0

Table 6 No correlation tests * :5% **:1%

determination	SiO2	TiO2	Al2O3	FeO	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	H2O-	H2O+	C	LOI	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Th	U	Zr	Hf	Nb	Ta	Cs	Ba	Rb	Sr
SiO2	–																																	
TiO2		–																																
Al2O3		**	–																															
FeO				–																														
Fe2O3	*			**	–																													
MnO		**	**			–																												
MgO	*						–																											
CaO	**				*		*	–																										
Na2O									–																									
K2O										–																								
P2O5		**	**			**					–																							
H2O-	*						*	*		*		–																						
H2O+	*			*	*			*					–																					
CO2	**				*		*	**				*	*	–																				
LOI															–																			
Ti		**	**			**					**					–																		
V											*						–																	
Cr	**				*			*					*	*				–																
Mn		**	**			**					**					**			–															
Fe	*						*	*				**		*						–														
Co																					–													
Ni																						–												
Cu																							–											
Zn	*				*			*					*					**						–										
Th		**	**			**					**					**			**						–									
U																										–								
Zr		**	**			**					**					**			**						**		–							
Hf		**	**			**					**					**			**						**		**	–						
Nb		**	**			**					**					**			**						**		**	**	–					
Ta		**	**			**					**					**			**						**		**	**	**	–				
Cs																										**					–			
Ba		**	*			**					**					**	*		**						**		**	**	**	**		–		
Rb																					*												–	
Sr	**				*		*	**				*	**	**				**		*				*										–
La		**	**			**					**					**			**						**		**	**	**	**		**		
Ce		**	**			**					**					**			**						**		**	**	**	**		**		
Pr		**	**			**					**					**			**						**		**	**	**	**		**		
Nd		**	**			**					**					**			**						**		**	**	**	**		**		
Sm		**	**			**					**					**			**						**		**	**	**	**		**		
Eu		*	*			**					*					*			**						*		**	**	*	*		*		
Gd		**	*			**					**					**			**						**		**	**	**	**		**		
Tb		**	**			**					**					**			**						**		**	**	**	**		**		
Dy		**	**			**					**					**			**						**		**	**	**	**		**		
Ho		**	**			**					**					**			**						**		**	**	**	**		**		
Er		**	**			**					**					**			**						**		**	**	**	**		**		
Tm		**	**			**					**					**			**						**		**	**	**	**		**		
Yb		**	**			**					**					**			**						**		**	**	**	**		**		
Lu		**	**			**					**					**			**						**		**	**	**	**		**		
Y		**	*			**					**					**	*		**						**		**	**	**	**		**		
Rh	*	*				*	**	**				*		**		*			*	**					*		*	*	*	*		*		*
Pt	*	*			*	*	*	**		*		*	*	**		*		*	*	*					*		*	*	*	*		*		**
Pd		*				*		*		**		*		*		*			*	*					*		*	*	*	*		*		*
Li									**																									
Be		**	**			**					**					**			**						**		**	**	**	**		**		
Mo																					*					*								
W		**	*			**					**					**			**						**		**	**	**	**		*		
Re																										**					**			
Ga		*	**			*					**					*	*		*						*		*	*	*	*		*		
In		**	**			**					**					**			**						**		**	**	**	**		**		
Tl		**	*			**					*					**	*		**						**		*	**	**	**		**		
Ge																										*								
Sn																						*												
P		*	*		*	**					*					*			**						*		**	**	*	*		*		
Bi	**				*		*	**					**	**				**						*										**
S				*																														
Te		**	**			**					*			*		**			**						**		**	**	**	**		**		

Table 6 No correlation tests * :5% **:1%

determination	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y	Rh	Pt	Pd	Li	Be	Mo	W	Re	Ga	In	Tl	Ge	Sn	P	Bi	S	Te
SiO2																																
TiO2																																
Al2O3																																
FeO																																
Fe2O3																																
MnO																																
MgO																																
CaO																																
Na2O																																
K2O																																
P2O5																																
H2O+																																
CO2																																
LOI																																
V																																
Cr																																
Mn																																
Fe																																
Co																																
Ni																																
Cu																																
Zn																																
Th																																
U																																
Zr																																
Hf																																
Nb																																
Ta																																
Cs																																
Ba																																
Rb																																
Sr																																
La	-																															
Ce	**	-																														
Pr	**	**	-																													
Nd	**	**	**	-																												
Sm	**	**	**	**	-																											
Eu	**	**	**	**	*	-																										
Gd	**	**	**	**	**	**	-																									
Tb	**	**	**	**	**	*	**	-																								
Dy	**	**	**	**	**	*	**	**	-																							
Ho	**	**	**	**	**	*	**	**	**	-																						
Er	**	**	**	**	**	**	**	**	**	**	-																					
Tm	**	**	**	**	**	*	**	**	**	**	**	-																				
Yb	**	**	**	**	**	*	**	**	**	**	**	**	-																			
Lu	**	**	**	**	**	*	**	**	**	**	**	**	**	-																		
Y	**	**	**	**	**	**	**	**	**	**	**	**	**	**	-																	
Rh		*	*	*	*			*	*	*	*	*	*	*		-																
Pt		*	*	*	*		*	*	*	*	*	*	*	*		**	-															
Pd	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	**	-														
Li																			-													
Be	**	**	**	**	**	*	**	**	**	**	**	**	**	**	**	*	*	*		-												
Mo																					-											
W	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**			*		**		-										
Re																							-									
Ga	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					*		*		-								
In	**	**	**	**	**	*	**	**	**	**	**	**	**	**	**	*	*	*		**		**		*	-							
Tl	**	**	**	**	**	*	**	**	**	**	**	**	**	**	**	*	*	*		**		*		*	**	-						
Ge																					*						-					
Sn																												-				
P	*	*	**	**	*	*	*	*	*	*	**	*	*	*	*		*	*		*		**			*				-			
Bi																*	*													-		
S																															-	
Te	**	**	**	**	**	*	**	**	**	**	**	**	**	**	**	*	*	*		**		**		*	**	**			*			-

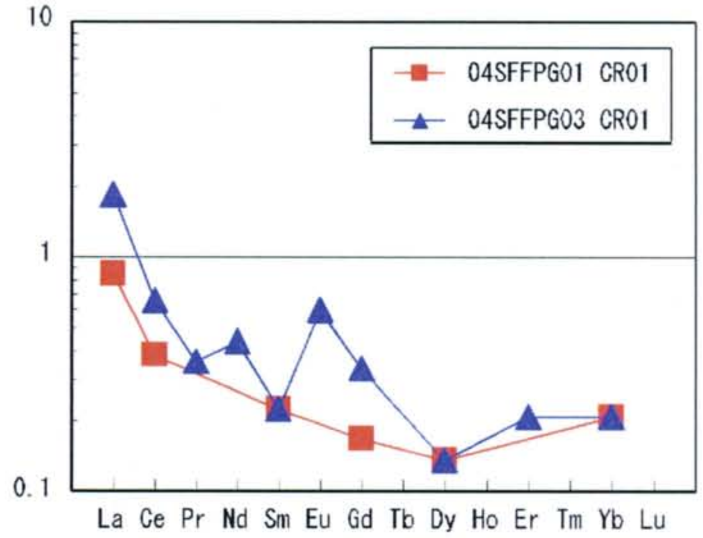


Fig 1. REE abundance patterns, normalized to chondritic abundances, for serpentinites from Fiji water.

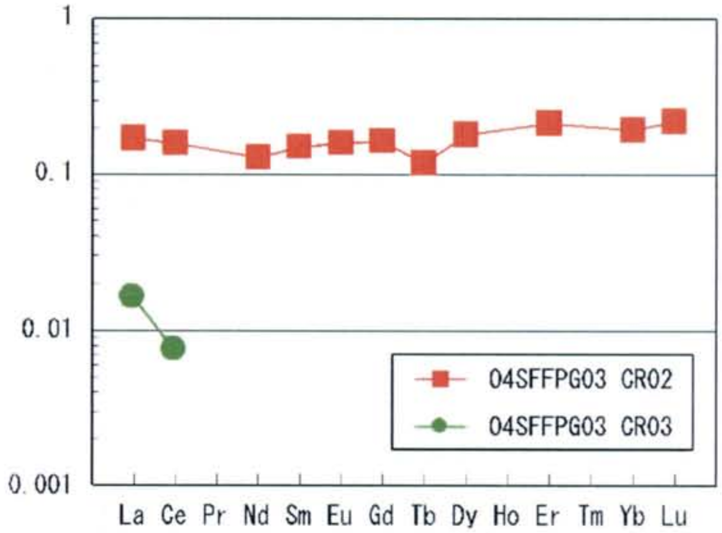


Fig 2. REE abundance patterns, normalized to the North American Standard Shale's abundances, for conglomerate and clay from Fiji Water.

5-3 3. Chemistry Sediments

3-1 Samples

The chemical analyses were conducted for the unconsolidated sediments (foraminifera sand) collected in the Central Hill (Table 1).

Table 1 Sample List of Unconsolidated Sediments

Area	Sampling No.	Depth (m)	Sampling Depth (m)	Geology	Sample No.
Central Hill	04SFMC11	1,946	0.10-0.15	foraminifera Sand	04SFMC11 CS01
			0.15-0.18	foraminifera Sand	04SFMC11 CS02

3-2 Analytical Method

A total of 34 elements, such as major elements, platinum group elements, gold, silver and trace elements, were analyzed. Analyzed elements, analytical methods, detection limits are given in Table 2. The chemical analyses were mainly conducted at ALS Chemex, Canada, except platinum group elements and Au, which were analyzed in Genalysis Laboratory Service Pty. Ltd, Australia. Before the chemical analyses desalination of the samples were conducted by supersonic washer using the deionized water for twenty for hours, repeating three times.

Table 2 Analyzed Elements and Analytical Method

Analyzed Elements (lower limit-upper limit)	Analytical Method
Al, Ca, Fe (0.01%-25%), Mg (0.01-15%), K, Na (0.01-10%), Ti (0.005-10%), P (10-10,000ppm), Mn (5-10,000ppm), Zn (2-10,000ppm), Cr, V (1-10,000ppm)	ICP-AES
Ba (10-10,000ppm), Pb (0.5-10,000ppm), As, Cu, Ni, Sr (0.2-10,000ppm), Co, W (0.1-10,000ppm), Mo (0.05-10,000ppm), Be, Sb (0.05-1,000ppm), Bi (0.01-10,000ppm), Cd (0.02-500ppm), Ag (0.01-100ppm)	ICP-AES and ICP-Mass
Mn (0.01-50%)*	Atomic Absorption Spectrometer
Rh (1ppb)	NiS collection Fire Assay + ICP-MS
Pt, Pd, Ru, Os, Ir (2ppb)	
Au (5ppb)	
Hg (0.01-100ppm)	Cold Vapor-Atomic Absorption Spectrometer
* only 04SFMC11 CS02	

3-3 Results

The analytical results of unconsolidated sediments are shown on Table 3

3-4. Considerations

Corresponding to the results of X-ray diffraction analysis of 04SFMC11with calcite and aragonite peaks, both samples CS01 and CS02 show high Ca contents reflecting abundant fragments of foraminifera included in the sediments. The both samples show high content of Mn suggesting the inclusions of manganese oxides particles or precipitates in the foraminifera sand. This coincides with the occurrence of todorokite identified by X-ray diffraction analyses in 04SFMC11 XRD02. Higher Mn associated by higher Ni and Cu in 04SFMC11 CS02 than in 04SFMC11 CS01 suggest that the former includes more particles or precipitates of manganese oxides than the latter.

Among platinum group elements (PGE) only Pt was detected, however, it is within the error range. Consequently, no significant PGE was contained in the samples.

Table 3 Analytical Results of Unconsolidated Sediments.

Area	Depth (m)	Sample No.	Al	Ca	Fe	Mg	K	Na	Ti	P	Mn	Zn	Cr	V	Ba	Pb	As	Cu	Ni
			%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Central Hill	1,946	04SFMC11 CS01	0.66	35.7	0.42	0.77	0.05	0.23	0.042	300	1730	25	49	12	50	6.7	12	27.8	16.5
		04SFMC11 CS02	0.61	35.3	0.43	0.94	0.08	0.25	0.042	310	26200*	51	82	16	70	4.1	<5	36.2	60.3

Area	Depth (m)	Sample No.	Sr	Co	W	Mo	Be	Sb	Bi	Cd	Ag	Hg	Os	Ir	Ru	Rh	Pt	Pd	Au
			ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb	ppb	ppb	ppb	ppb	ppb	ppb
Central Hill	1,946	04SFMC11 CS01	1465	2.5	0.2	0.34	0.09	0.28	<0.01	0.39	0.12	0.02	<d.l.	<d.l.	<d.l.	<d.l.	2	<d.l.	<d.l.
		04SFMC11 CS02	1435	4.9	1	5.32	<0.05	1.52	<0.01	0.99	0.13	0.02	<d.l.	<d.l.	<d.l.	<d.l.	2	<d.l.	<d.l.

5-3 4. Microfossils in Sediments

4-1 Sample for Fossil Identifications

Fossil identification was conducted for unconsolidated sediments collated in the Central Hill by MC (Table 1).

Table 1 Sample for Fossil Identification

Area	Sampling No.	Depth (m)	Location of sample (m)	Lithology	Sample No.
Central Hill	04SFMC11	1,946	0.10-0.18	foraminifera sand	04SFMC11 FS01

4-2 Analytical Methods and Results

For determination of sedimentation age of the unconsolidated sediments, inspections of planktonic foraminifer, ichthyolith and radiolaria were conducted. The analytical methods and results are given below on each fossil type basis. The fossil inspections were conducted by following researchers as shown on Table 2.

Table 2 Inspector of Fossils

Fossil Type	Inspector	Institutions
planktonic foraminifer	Motoyoshi Oda	Professor, Tohoku University
ichthyolith	Kaoru Oogane	PhD student, Tohoku University
radiolaria	Noritaka Suzuki	Assistant Professor, Tohoku University

4-2-1 Planktonic Foraminifer

(1) Analytical Method

To a beaker, 30g of unconsolidated sediments was taken and each individuals fossil was separated rinsing by 3% hydrogen peroxide. After filtering by 63-micrometer mesh, dried by oven. Planktonic foraminifers of more than 150 micrometer across were identified under microscope magnifying 40 times.

(2) Results

The planktonic foraminifers shown on Table 3 were identified from the unconsolidated sediments.

As the identified planktonic foraminifers, such as *Globigerinoides rubber*, *G. sacculifer*, *G. conglobatus*, *Globorotalia*、*Sphaeroidinella dehiscens* and *Pulleniatina* *obliquiloculata,* belong to tropical to sub-tropical group (Be, 1977), the biostratigraphic standard of the low latitude (Blow, 1969; Berggren et al., 1985、1995) can be applied for geological age determination.

Table 3 Results of Planktonic Foraminifer Identification

Species	Abundance
G. bulloides d'Orbigny	R
Globigerinella aequilateralis (Brady)	R
G. calida Parker	R
Globigerinita glutinata (Egger)	R
G. conglobatus (Brady)	F
G. ruber (d'Orbigny)Pink	C
G. ruber (d'Orbigny)White	R
G. sacculifer(Brady)	C
Globorotalia crassaformis (Galloway and Wissl	R
G. menardii (Parker, Jones and Brady)	F
G. truncatulinoides (d'Orbigny)	R
G. tumida (Brady)	R
Neogloboquadrina dutertrei (d'Orbigny)	R
O. universa (d'Orbigny)	R
Pulleniatina obliquiloculata (Parker and Jones)	R
Sphaeroidinella dehiscens (Parker and Jones)	R

R: Rare,F: Few,C: Common

Following biostratigraphic events and geological ages were used for estimating the geological age of this area.

1) extinction of pink individual of *Globigerinoides ruber* : 0.12Ma
2) appearance of *Globigerinella calida calida* : 0.3 Ma
3) extinction of *Globorotalia tosaensis* :0.6 Ma
4) appearance of *Globorotalia truncatulinoides* :2.0Ma

From the evidences that *Globorotalia truncatulinoides* occurs and *Globorotalia tosaensis* was not found and that *Globigerinella calida calida* and pink individuals of *Globigerinoides rubber* occur, the geological age of this sample is estimated to be late Pleistocene.

4-2-2 Ichthyolith

(1) Analytical Method

The ichthyolith fossils were collected by following manner. At first, sediments sample was rinsed by 3% hydrogen peroxide to separate individual fossils. After rinsing by water, calcareous materials such as foraminifer were removed by 5% acetic acid. Then, it was filtered by 63-micrometer mash and the remnants on the mesh were collected for picking up ichthyolith individuals by microscope. The collected Ichthyolith fossils were sealed in the slide glass and the identification of Ichthyolith was conducted using the biological microscope.

Estimation of geological age was done based don Doyle and Riedel (1985), which was most recently established biostratigraphy of Ichthyolith.

(2) Results

The sub-types of Ichthyolith related to determining geological age are listed in Table 4 and photographs of typical Ichthyolith found in the sample are shown in Figure 1.

Table 4 Sub-Types of Ichthyolith

Sub-Type	Age
Flexed triangle 120-128	0.0Ma-32.4Ma
Rectangular saw-toothed	0.0Ma-32.4Ma
Triangle with high inline apex	0.0Ma-32.4Ma
Triangle with base angle	0.0Ma-32.4Ma
Small triangle with long striation	0.0Ma-32.4Ma

All of the sub-types of Ichthyolith included in the sample, such as *Rectangular saw-toothed*、*Triangle with high inline* apex、*Triangle with base angle* and *Small triangle with long striation*, belong to the sub-types that appeared after 32.4 Ma. Consequently, geological age of 0.0Ma to 32.4Ma was estimated for the sample. This corresponds to the evidence that the sub-type of Ichthyolith that disappeared before 32.4Ma were not found in the sample.

4-2-3 Radiolaria

(1) Analytical Method

For concentrating siliceous microfossils, calcareous part was removed by conc-hydrochloric acid, and hydrogen peroxide and surface-active agent, calgon, were used for dissolving organic materials and clay minerals, respectively. Then, the sample was filtered by 38-micrometer mesh and the remnants were investigated by microscope. The microscopic observation resulted in finding no fragment of radiolaria. The sample was further examined by suspended materials separation method without using chemicals for concentration of siliceous microfossils. The result of microscopic observation of the remnants obtained by this method revealed only one fragment with similar appearance to radiolaria.

(3) Results

Since only one fragment with similar appearance to radiolaria was fond in the sample, it was impossible to estimate geological age and paleoenvironment form the sample. It is known that species of radiolaria are rare in the area close to the sampling location (177-25.847E, 16-5.692S) located at the boundary zone of nonproductive zone of radiolaria in the South Pacific (eg. Lombari and Boden 1985). The evidence of no radiolaria found in the sample suggests that the area of the sampling location is probably situated inside the nonproductive zone of radiolaria.

4-3 Conclusions

The results of the fossil identification are given in Table 5.

Table 5 Results of Fossil Identification

Area	Sampling No.	Sampling Depth (m)	Sample No.	Ichthyolith	Planktonic Foraminifer	Radioraia
Central Hill	04SFMC11	0.10-0.18	04SFMC11 FS01	0.0-32.4Ma	Late Pleistocene	very poor occurrence

The fossil identification suggests that the sedimentation of the sample started in late Pleistocene in the nonproductive zone of radiolaria.

Plate

Photomicrographs of Microfossils

A. Ichthyolith・Planktonic Foraminifer

(Scale bar is 100 μm)

fig. 1 *Flexed triangle 120-128*

Photo ID P1260217

fig. 2 *Rectangular saw-toothed*

Photo ID P1260221

fig. 3 *Triangle with high inline apex*

Photo ID P1260227

fig. 4 *Triangle with base angle*

Photo ID P1260235

fig. 5 *Small triangle with long striation*

Photo ID P1260253

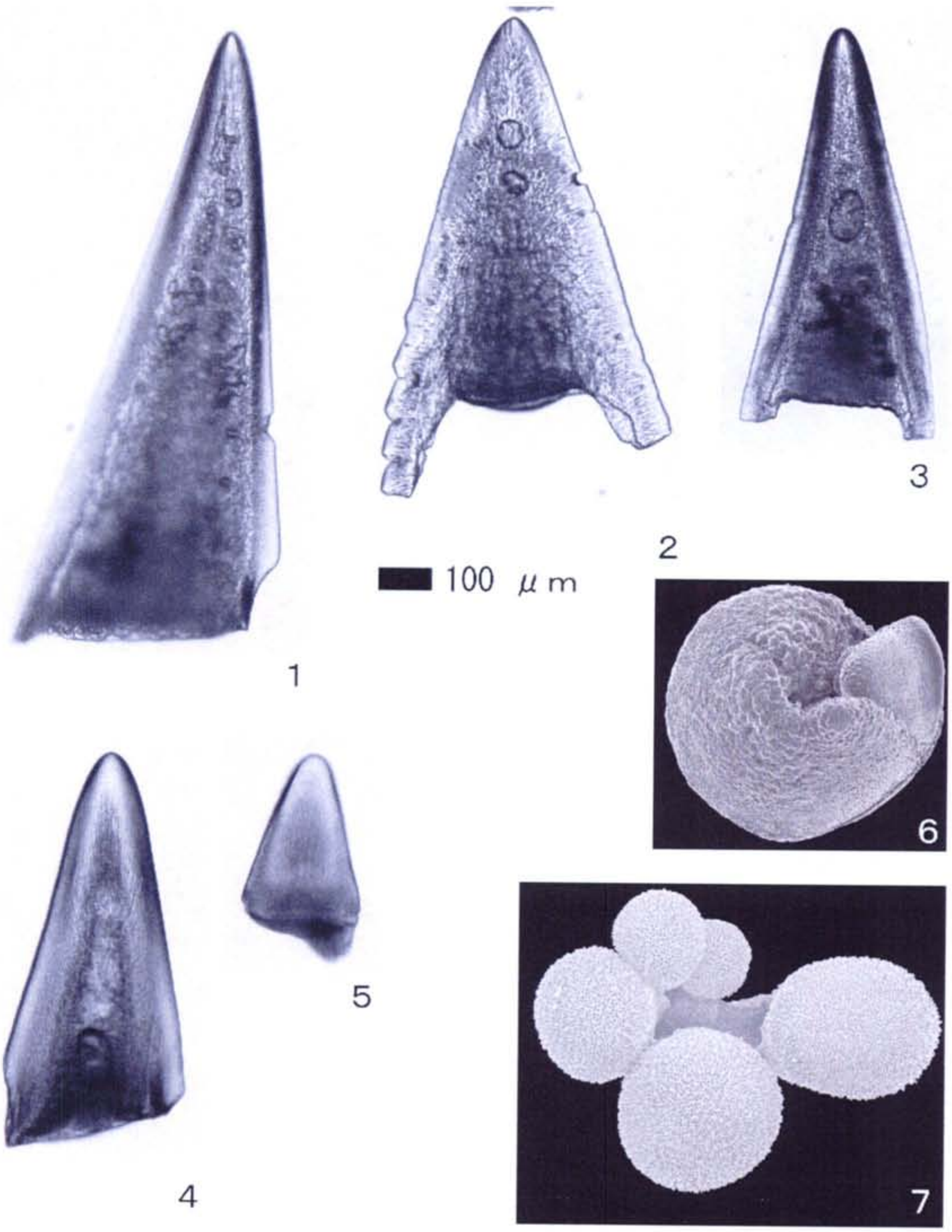
fig. 6 *Globorotalia truncatulinoides*

Photo ID image004

fig. 7 *Globigerinella calida calida*

Photo ID cal.1-u070

Plate 1



Appendix 6

Environmental Survey

Appendix 6 Environmental Survey

Contents

1. Objectives

The environmental survey was carried out in designated areas as a baseline study to evaluate the magnitude of mining impacts on deep-sea environment. The survey was done to understand: 1) the condition of water quality and the distribution of microorganisms in the water (referred hereafter as the, "water quality/ bacterioplankton survey"), and 2) the condition of bottom-sediment properties and the composition of benthic organisms (referred hereafter as the, "bottom sediment and benthic organism survey").

2. Sampling Area

The areas selected for sampling are shown in Figures 2-1 and 2-2. Two sampling sites were used for the research: Central Hill of 16°00'S,177°20'W and ERZA of 16°20'S, 177°20'W. Central Hill is a seamount situated at a water depth of 2,500 m and ERZA has a fairly level topography located at a water depth of 2,000 m.

3. Materials and Methods

3-1 Study Subjects

3-1-1 Water Quality/Bacterioplankton Survey

(1) Water quality: water temperature and salinity

(2) Microorganisms: bacterioplankton

3-1-2 Bottom Sediment and Benthic Organism Survey

The following surveys were conducted using a multiple corer (MC). Prior to sampling, a video observation was carried out to select sites with large accumulation of sediments. Samples for macrobenthic organisms were obtained from mineral samples, which were collected using a power glove (FPG) or arm dredge (AD).

(1) Bottom-sediment properties: water content, calcium carbonate, total organic carbon, total nitrogen, total sulfide, and specific gravity.

(2) Benthic organisms: sedimentary bacteria, meiobenthos, and macrobenthos.

3-2 Survey Methods

3-2-1 Observation, Sampling, and Processing of Samples

(1) Water quality/Bacterioplankton Survey

Water temperature and salinity were measured using a CTD (SEA-BIRD: MODEL 9 PLUS) attached to a rosette sampler (RO). Measurements of these parameters were carried out from the surface layer to 10 m depth above the sea floor. The instrument was dropped at 0.5 m/sec, and measurement interval was set as once per second.

Samples for bacterioplankton was taken using a Niskin water sampler (with a capacity of 1.7 liters) attached to an RO, from 12 layers (10 m, 50 m, 75 m, 100 m, 125 m, 150 m, 175 m, 200 m, 250 m, 300 m, 500 m, and 1,000 m) from the sea floor. Samples were treated accordingly as described in Table 3-2-1.

(2) Bottom sediment and benthic organism survey

Sediment samples for the "bottom sediment and benthic organism survey" (excluding macrobenthos) were taken using MC. To minimize the possibility of hitting gravels, thus reducing the incidence of core obstruction, the number of cores was reduced from eight to four. Samples were sliced every 1 cm from the surface to 8 cm depth of the sediment. Samples were then treated accordingly as described in Table 3-2-1.

Table 3 - 2 - 1 Sample processing and preservations

Subject	Sample processing and preservations
Bacterioplankton	Fixed by glutaraldehyde (1 % v/v) and stained by DAPI (1μg/ml), filtered by nuclepore filter (0.2μm), mounted on a slide glass; frozen
Water Content, Specific Gravity, $CaCo_3$、TOC、T－N	Frozen
T－S	Fixed by Zinc ammine; refrigerated
Sedimentary Bacteria	Fixed by glutaraldehyde (1 % v/v); refrigerated
Meiobenthos	Fixed by neutralized formalin (10 % v/v) and stained by Rose Bengal; refrigerated
Macrobenthos	Fixed by neutralized formalin (10 % v/v)

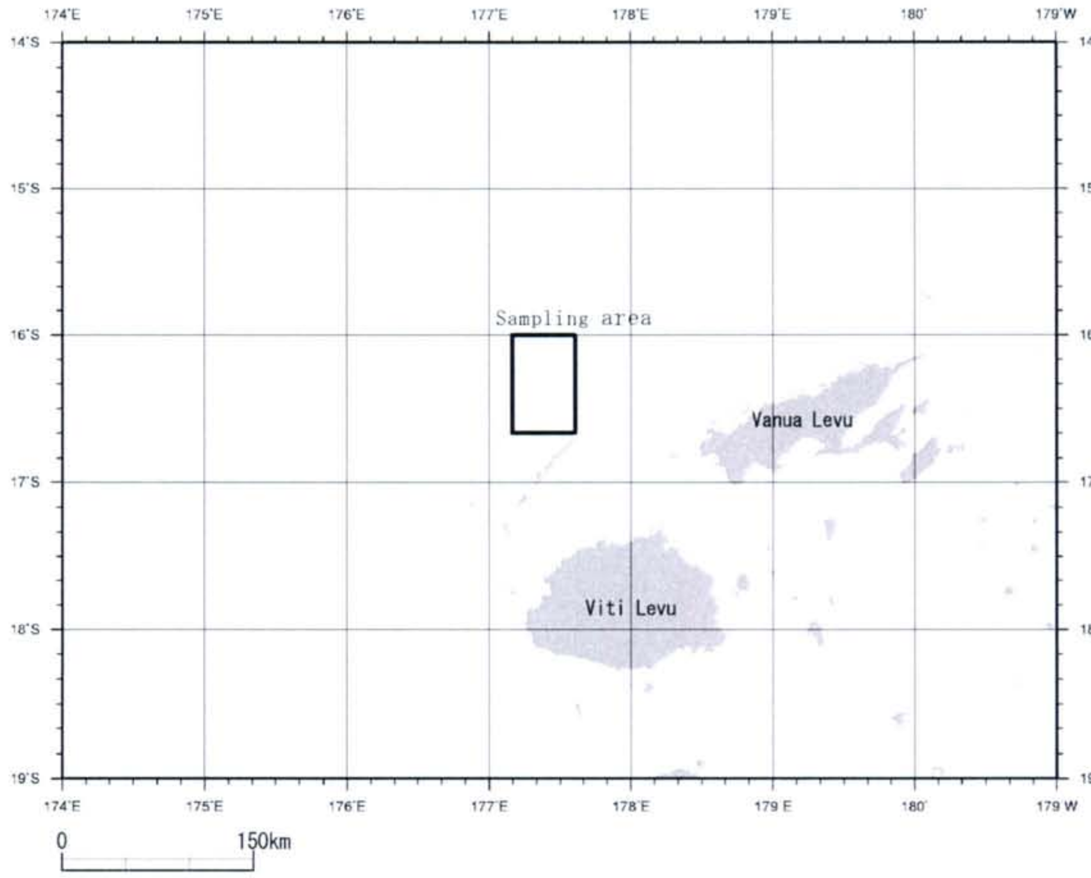


Figure 2 - 1 Sampling area (1)

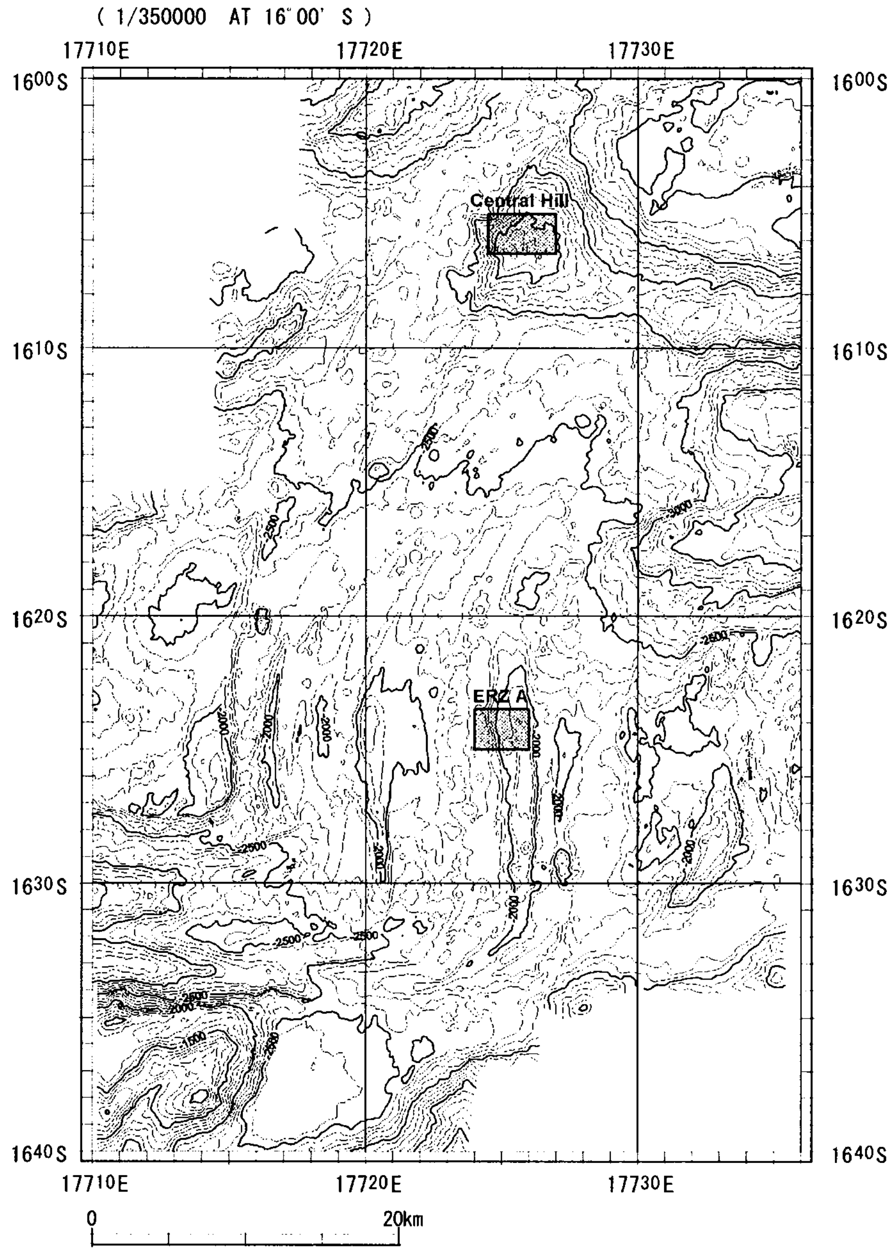


Figure 2 - 2 Sampling area (2)

3-2-2 Analysis of Samples

(1) Water quality/Bacterioplankton survey

1) Bacterioplankton

Bacterioplankton on the nuclepore filters were counted using an epiflourescence microscope. Abundance was expressed as the total number of bacteria per unit volume of seawater.

(2) Bottom sediment and benthic organism survey

1) Water Content

The wet sample was weighed, desiccated in a dryer (60□C) until a constant weight was obtained, and then weighed again.

2) Calcium Carbonate

After the water content of the sample had been measured, the total carbon in the dry sample was measured with a CHN analyzer (MT-5 made by Yanaco). The amount of inorganic carbon was obtained as the difference between the total carbon and the organic carbon. Then, assuming that the inorganic carbon existed in the form of calcium carbonate, the quantity of this compound was calculated from the element ratio.

3) Total Organic Carbon (TOC) and Total Nitrogen (T-N)

After the water content had been determined, the dry sample was measured with a CHN analyzer (MT-5 made by Yanaco) to find the total amounts of carbon and nitrogen. The sample was treated with 4-N hydrochloric acid and reaction was allowed to occur for about one hour to remove the inorganic carbon. The sample was then desiccated again and measured with the CHN analyzer in the same way to find the organic carbon content.

4) Total Sulfide (T-S)

The fixed sample was filtered with a glass fiber filter (GF/F) and the residue was distilled under an acidic condition using sulfuric acid. The extract obtained through filtration was re-fixed in zinc acetate dihydrate solution (10%) and was titrated using a sodium thiosulfate pentahydrate solution (1/100 N). The data obtained through titration was standardized into a unit of dry weight using water contents measured previously, so as to determine the total sulfide.

5) Specific Gravity

The sample was dried to a constant weight at 110□C and then milled in an agate mortar. This was measured into a specific gravity bottle to about 10 grams. Distilled water was added into the sample and was heated in a water bath chamber for 4 hours.

It was left untouched for a whole day after which, the temperature and weight of the specific gravity bottle were measured.

6) Sedimentary Bacteria

The bacteria bonding to the bottom sediment particles were exfoliated using an ultrasonic treatment into a settled solution, and then a fractional quantitation of the supernatant liquid was taken. This was stained with a DAPI (with a final concentration of 1 μg/ml) and filtered. The trapped sediment was mounted on a glass slide and the number of bacteria was counted using an epiflourescence microscope. The total amount of bacteria per unit quantity of dry sediment was calculated from the dry weight of the bottom sediment material, which had been measured separately.

7) Meiobentos

The sample stained with rose bengal was sieved by of 32 μm and 300 μm mesh sieve. Organisms were identified and counted under a microscope.

8) Macrobenthos

The sample was sieved using a 300 μm mesh sieve to separate out the sand and mud. Organisms that were trapped in the sieve were identified and counted.

4. Results

4-1 Survey Stations

The water quality/bacterioplankton survey were carried out at two stations (Central Hill: 04SFRO06, ERZA: 04SFRO07) while the sediment properties and benthic organism (excluding macrobenthic) surveys were carried out at three stations in Central Hill (04SFMC09, 04SFMC10, 04SFMC11). The macrobenthos survey as carried out at four stations in the Central Hill (04SFFPG01, 04SFFPG02, 04SFFPG03, 04SFAD07) and at one station in the ERZA (04SFAD05), (Figures 4-1-1 and 4-1-2).

4-2 Water Quality and Bacterioplankton

4-2-1 Water Quality

(1) Water temperature

The water temperature ranged from 28.6°C (at the surface layer) to 2.3°C (at 1,914 m depth) at 04SFRO06 and from 28.8°C (at the surface layer) to 2.2°C (at 1,923 m depth) at 04SFRO07. The vertical distribution of the water temperature of the whole water column did not significantly differ between the two stations. The temperature decreased remarkably from the surface to 600 m depth and minimal change was observed from 600 m to 2,000 m depth (Figure 4-2-1).

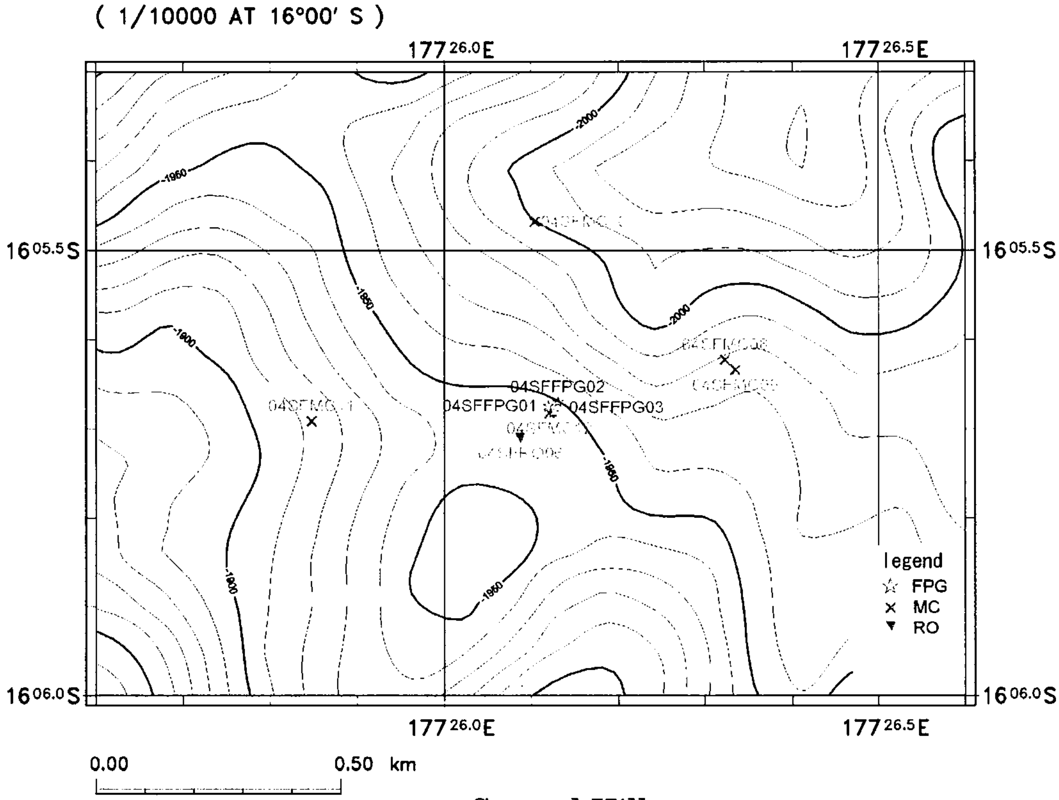
(2) Salinity

At 04SFRO06, the salinity increased at around 30 m, showing a maximum value (about 35.2 PSU) at around 170 m. However, it decreased remarkably until around 700 m depth (about 33.8 PSU) and then increased gradually again until about 2,000 m (Figure 4-2-1). At 04SFRO07, the salinity increased at around 20 m, reaching a maximum of 35.9 PSU at around 130 m, and decreased remarkably to 34.4PSU around 700 m, and then increased gradually again until around 2,000 m (Figure 4-2-1).

4-2-2 Bacterioplankton

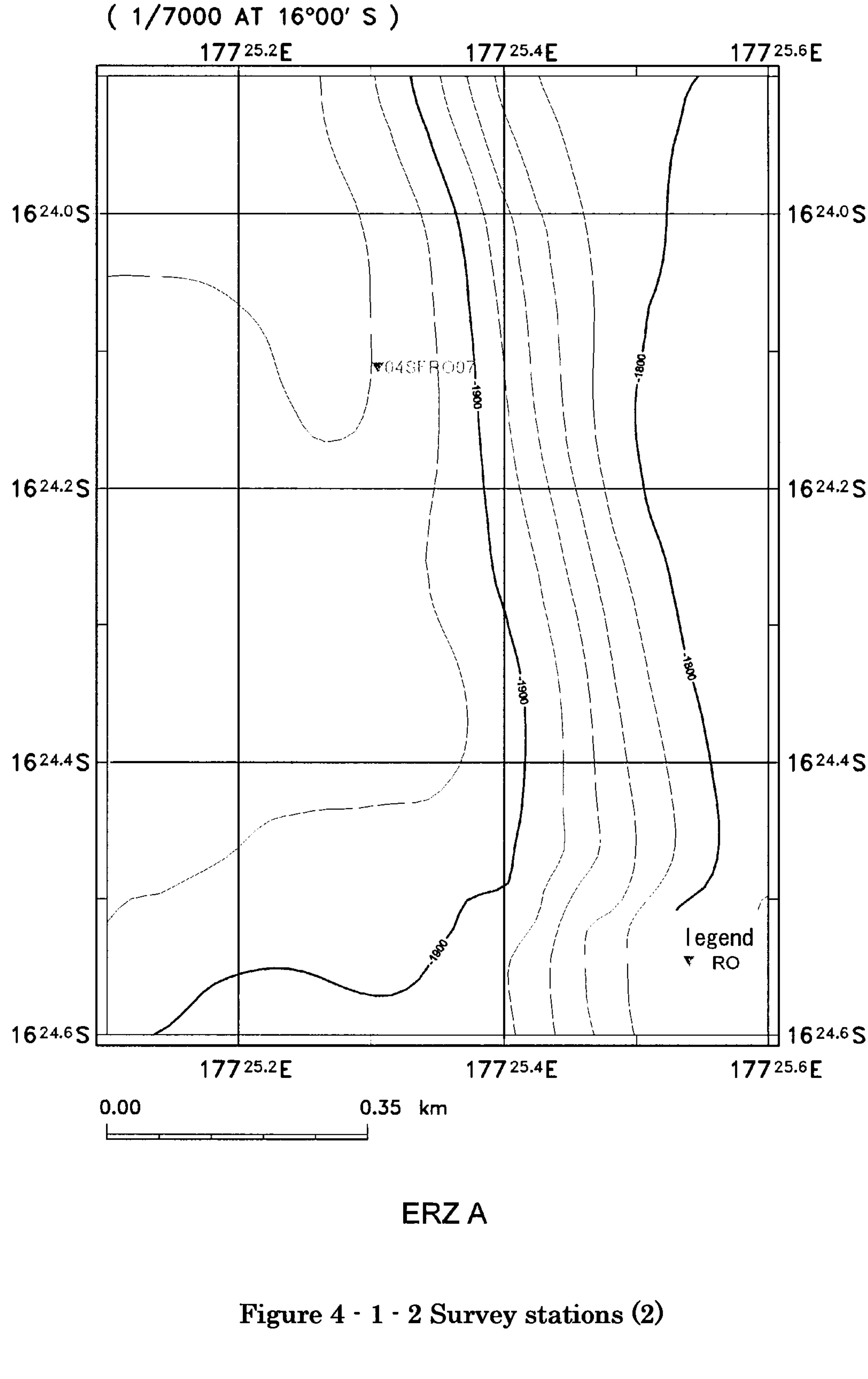
At 04SFRO06, the abundances of bacterioplankton showed a maximum abundance of 1.86×10^4 cells / ml at 914 m depth, but decreased to 1.04×10^4 cells / ml at 1,616 m depth. In the deeper layer, abundances showed an oscillating pattern, showing a maximum (1.33×10^4 cells/ml) at 1,716 m and a minimum (9.55×10^3 cells/ml) at 1,787 m depth(Figure 4-2-2 and Appendix 1).

At 04SFRO07, the abundances were 1.40×10^4 cells / ml at 932 m depth and observed a maximum (1.53×10^4 cells / ml) at 1,681 m depth. In the deeper than this layer, it decreased to 1.02×10^4 cells / ml at 1,806 m depth (Figure 4-2-2 and Appendix 1).



Central Hill

Figure 4 - 1 - 1 Survey stations (1)



ERZ A

Figure 4 - 1 - 2 Survey stations (2)

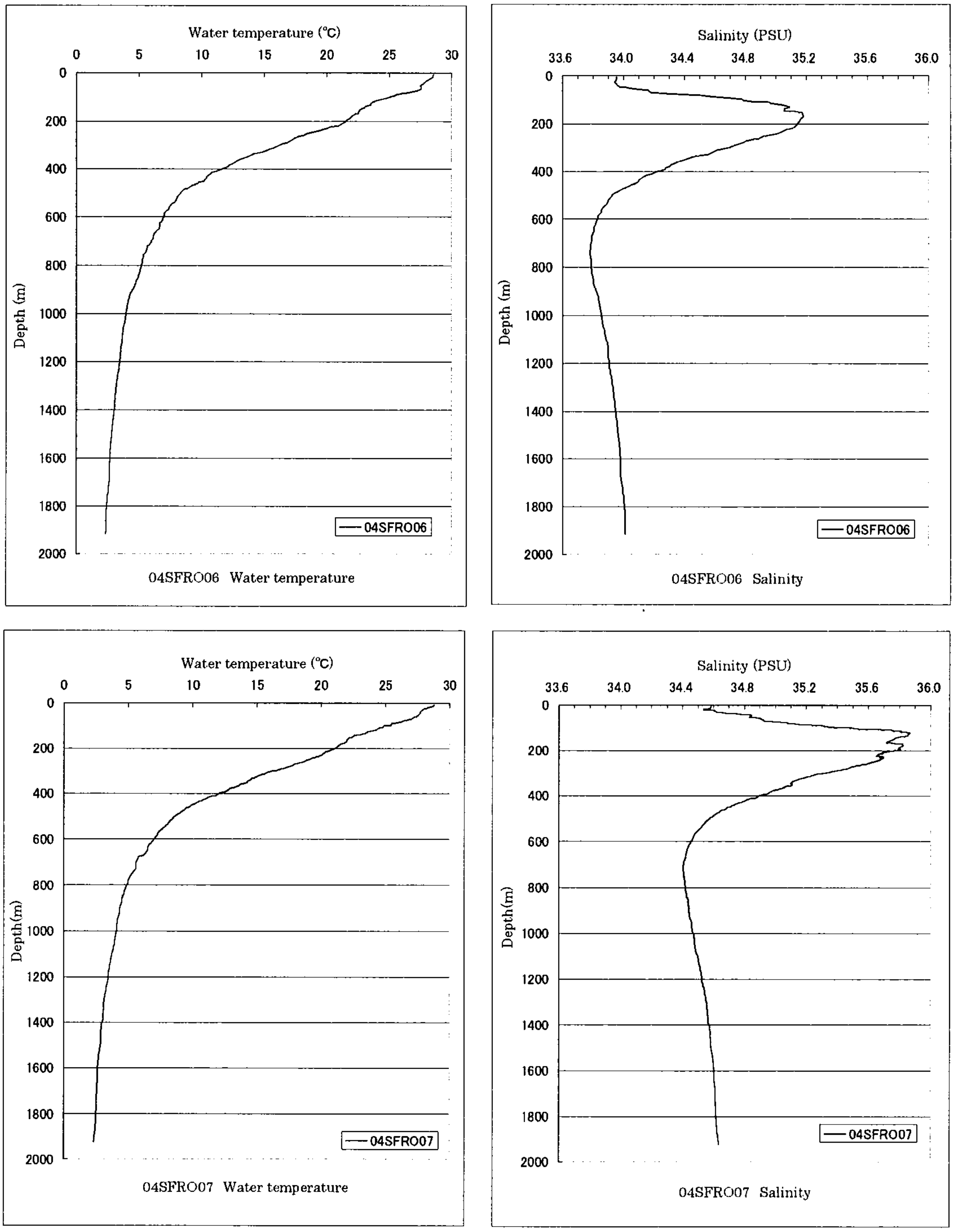


Figure 4 - 2 - 1 Vertical profiles of water temperature and salinity

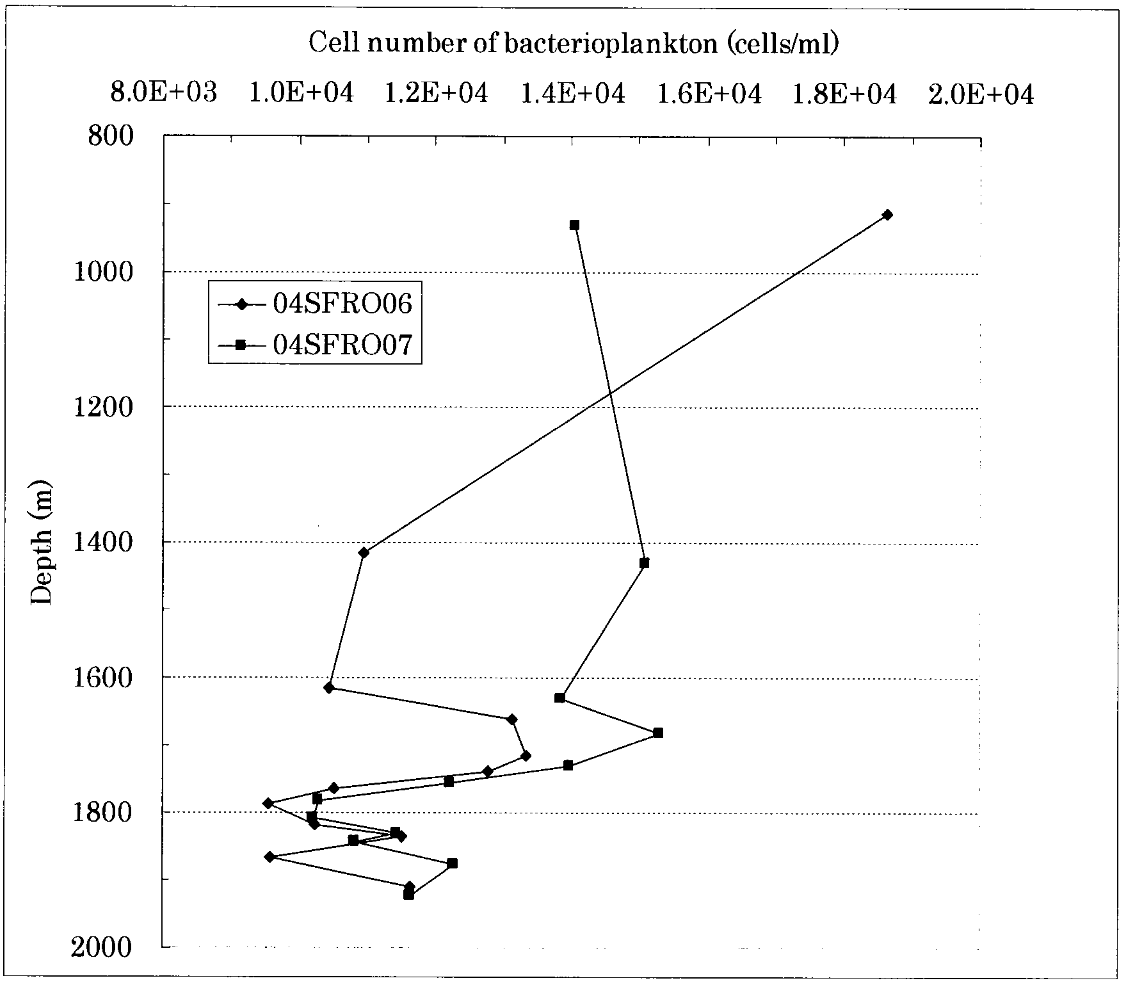


Figure 4 - 2 - 2 Distribution of bacterioplankton

4-2-3 Summary

A T-S diagram of depths below 1,400 m was prepared to confirm hydrothermal plumes for both station (Figures 4-2-3 and 4-2-4). Regression lines between water temperature and salinity from 1,400 m to 1,600 m and data measured at depths of 1,400 meters and deeper were drawn. Both stations belong to low water temperature and high salinity regions. Both stations showed a shift towards the direction having the higher value toward the sea bed as estimated from the regression formula of water temperature and salinity. The difference for each depth between water temperature and the value found using the regression formula is shown in Figure 4-2-5. This result showed that below 1,600 m the difference was large implying that there is water temperature abnormality at this depth. In addition, the depth exhibiting temperature abnormality corresponded to the layer in which bacterial cell number was increased.

Generally, it may be thought that plumes form in the vicinity of the survey sea area due to the release of thermal water that caused the existence anomalous water temperature toward the sea bed. This phenomenon also may have caused the increase in the number of bacteria assumed to be utilizing the chemical components of the plumes as energy source. Further investigation on the activities of manganese, methane and other chemical components as an indicator of hydrothermal activity, is suggested.

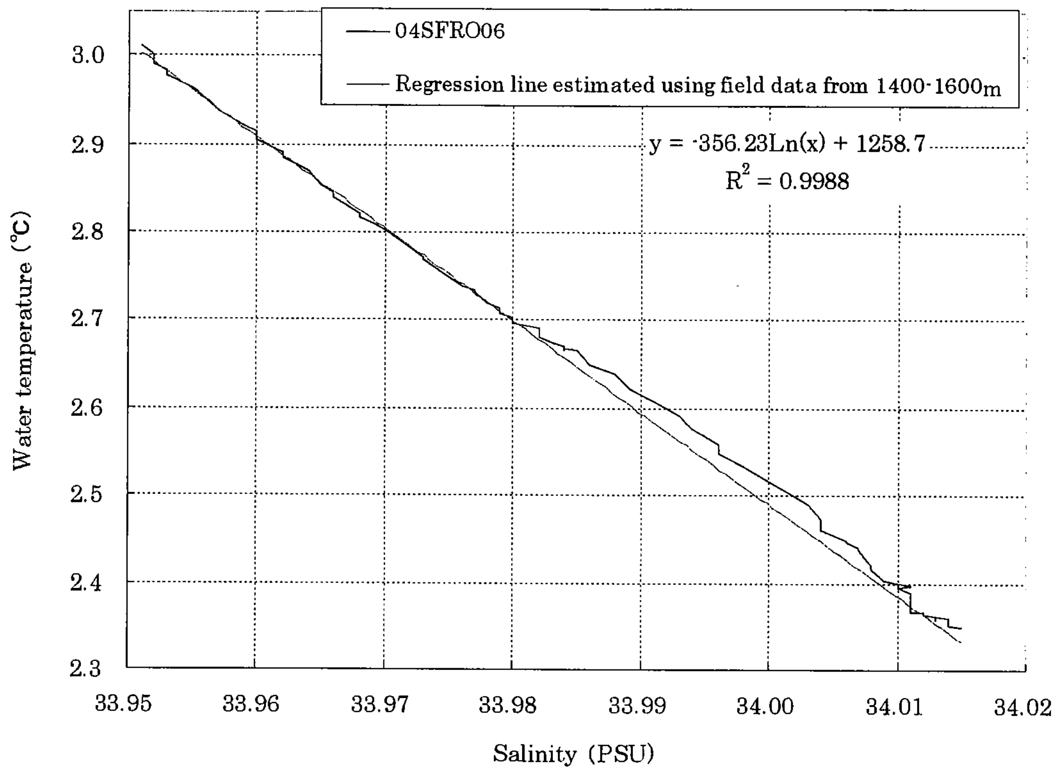


Figure 4 - 2 - 3 T/S diagram below 1400m depth at 04SFRO06 and regression line estimated using field data from 1400-1600m

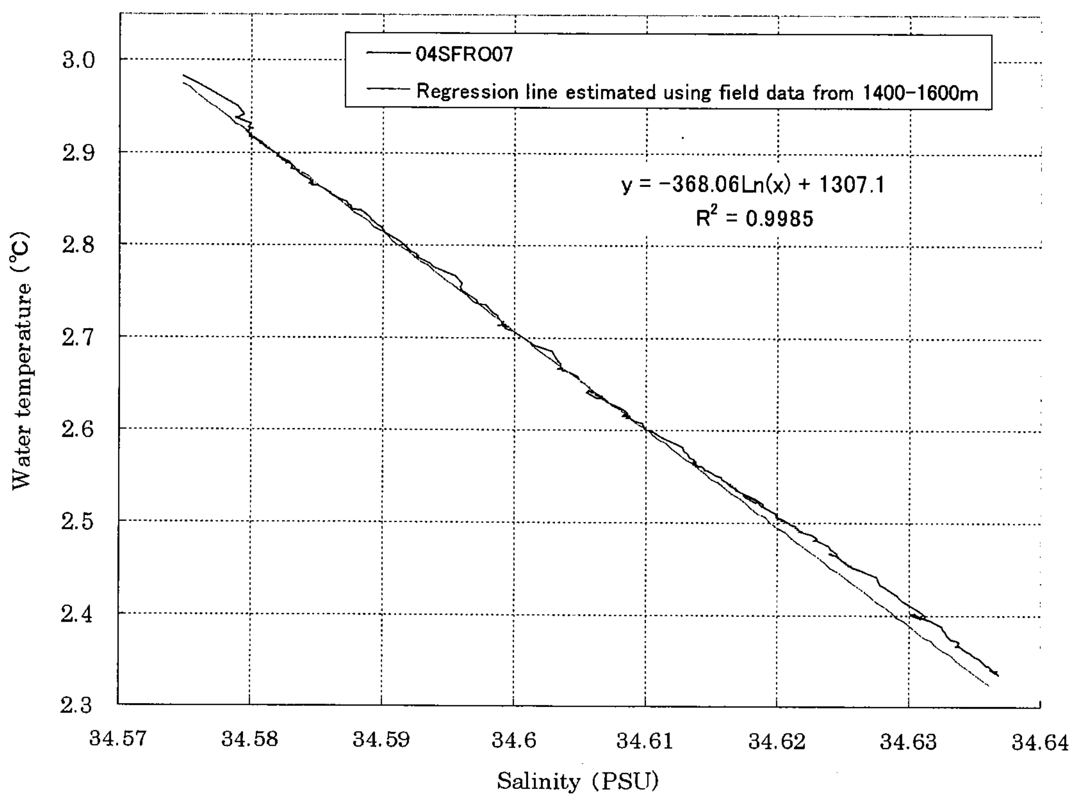


Figure 4 - 2 - 4 T/S diagram below 1400m depth at 04SFRO07 and regression line estimated using field data from 1400-1600m

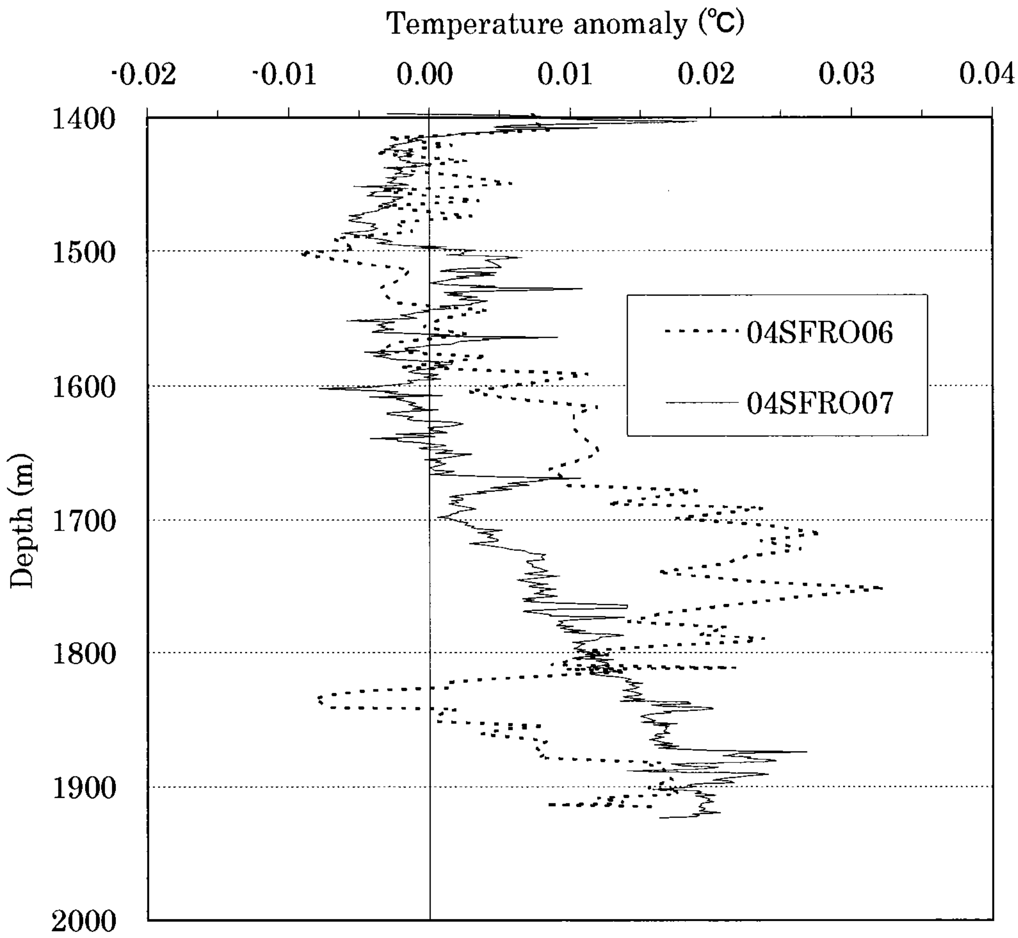


Figure 4 - 2 - 5 Vertical profile of water temperature anomaly. Water temperature anomaly is derived as the difference between field data and estimated data using equations shown in Figure 4-2-3 and 4-2-4

4-3 Bottom Sediment and Benthic Organism

4-3-1 Bottom Sediment

(1) Water Content

The vertical distributions of the water content at each station were shown in Figure 4-3-1 and Table 2. At 04SFMC09, the average water content was 53.2% from the surface to 1 cm layer, and 47.2-48.9% in depths greater than 1 cm. At 04SFMC10, the value was 54.9% on average in the 0-1 cm layer, and 47.3-50.7% deeper than 1 cm depth. At 04SFMC11, the water content was 51.0% in the 0-1 cm layer showing a tendency to decrease from the 1 cm depth to the deeper layers, and the minimum value was 43.9% in the 7-8 cm layer.

At 04SFMC09 and 04SFMC10, the water content was higher in 0-1 cm layer, and showed lower value in the layers between 3 and 5 cm; it increased slightly below 5 cm. At 04SFMC11, however, the water content decreased from the surface to the 8 cm.

(2) Calcium Carbonate (CaCO3)

The vertical distributions of calcium carbonate at each station were shown in Figure 4-3-1 and Table 2. At 04SFMC09, the minimum value for calcium carbonate was 70.2% on average in the 1-2 cm layer, and the maximum value was 77.6% on average in the 6-7 cm and 7-8 cm layers. At 04SFMC10, the minimum value for calcium carbonate was 71.2% on average in the 0-1 cm layer, and the maximum value was 83.2% on average in the 7-8 cm layer. At 04SFMC11, the minimum value for calcium carbonate was 78.3% on average in the 0-1 cm layer, and the maximum value was 94.1% on average in the 5-6 cm layer.

At 04SFMC09 and 04SFMC10, the concentrations of calcium carbonate showed the tendency to increase from the surface to deeper layers. However, the concentrations of calcium carbonate at 04SFMC11 were higher in all the layers than at the other two stations, and there was the greatest value at the 5-6 cm layer.

(3) Total Organic Carbon (TOC)

The vertical distributions of the total organic carbon at each station were shown in Figure 4-3-1 and Table 2. At 04SFMC09, the concentration of total organic carbon was 1.85 mg/g-dry on average in the 0-1 cm layer and 1.32 -1.61 mg/g-dry on average in the deeper than 1 cm depth. At 04SFMC10, the total organic carbon was 2.04 mg/g-dry on average in the 0-1 cm layer and 1.43-1.84 mg/g-dry in the deeper than 1 cm depth. At 04SFMC11, the maximum value of total organic carbon was 1.93 mg/g-dry in the 2-3 cm layer, and the minimum value was 1.22 mg/g-dry in the 5-6 cm layer.

At 04SFMC09 and 04SFMC10, the concentrations of total organic carbon were highest in the 0-1 cm layer, and only a little variation was observed deeper than 1 cm depth vertically. However, at 04SFMC11, the concentrations were higher in the layers between 0 to 3 cm and significantly lower in the layers between 4 to 8 cm.

(4) Total Nitrogen (T-N)

The vertical distributions of total nitrogen at each station were shown in Figure 4-3-1 and Table 2. At 04SFMC09, the concentrations of total nitrogen were between 0.21 -0.30 mg/g-dry on average and only a little variation was observed vertically. At 04SFMC10, the concentration was 0.33 mg/g-dry on average in the 0-1 cm layer, and 0.23-0.27 mg/g-dry and stable deeper than 1 cm depth. At 04SFMC11, the maximum value was 0.40 mg/g-dry on average in the 2-3 cm layer, and the minimum value was 0.24 mg/g-dry, in the 5-6 cm layer. Both the total nitrogen and total organic carbon were higher at the surface layer and significantly lower in the deeper layers.the maximum value of total organic carbon was 1.93 mg/g-dry in the 2-3 cm layer, and the minimum value was 1.22 mg/g-dry in the 5-6 cm layer.

(5) Total Sulfide (T-S)

The concentrations of total sulfide were below the detection limit in all the samples at all the stations (Table 2).

(6) Specific Gravity

The vertical distributions of the specific gravity at each station were shown in Figure 4-3-1 and Table 2. At 04SFMC09, the specific gravity values were 2.75-2.79 on average in all the layers. Similarly, at 04SFMC10, the specific gravity values were 2.76-2.78 on average in all the layers. At 04SFMC11, the lowest value was 2.74 in the 0-1 cm layer, and the highest was 2.83 in the 7-8 cm layer.

(7) The correlation between measurements for the bottom sediment

The correlation between measurements for the bottom sediment is shown in Figure 4-3-2, and the correlation matrix is shown in Table 4-3-1. The strong correlation was observed between the water content and the total organic carbon as well as between total organic carbon and total nitrogen. The correlation coefficients were 0.69 and 0.57, respectively. No correlations were found among other properties.

Table 4 - 3 - 1 Correlation matrix of sediment properties

Properties	Water content	$CaCO_3$	TOC	T-N	Specific gravity
Water content	1.00				
$CaCO_3$	-0.47	1.00			
TOC	0.69	-0.29	1.00		
T-N	0.26	0.21	0.57	1.00	
Specific gravity	-0.20	0.31	-0.23	-0.18	1.00

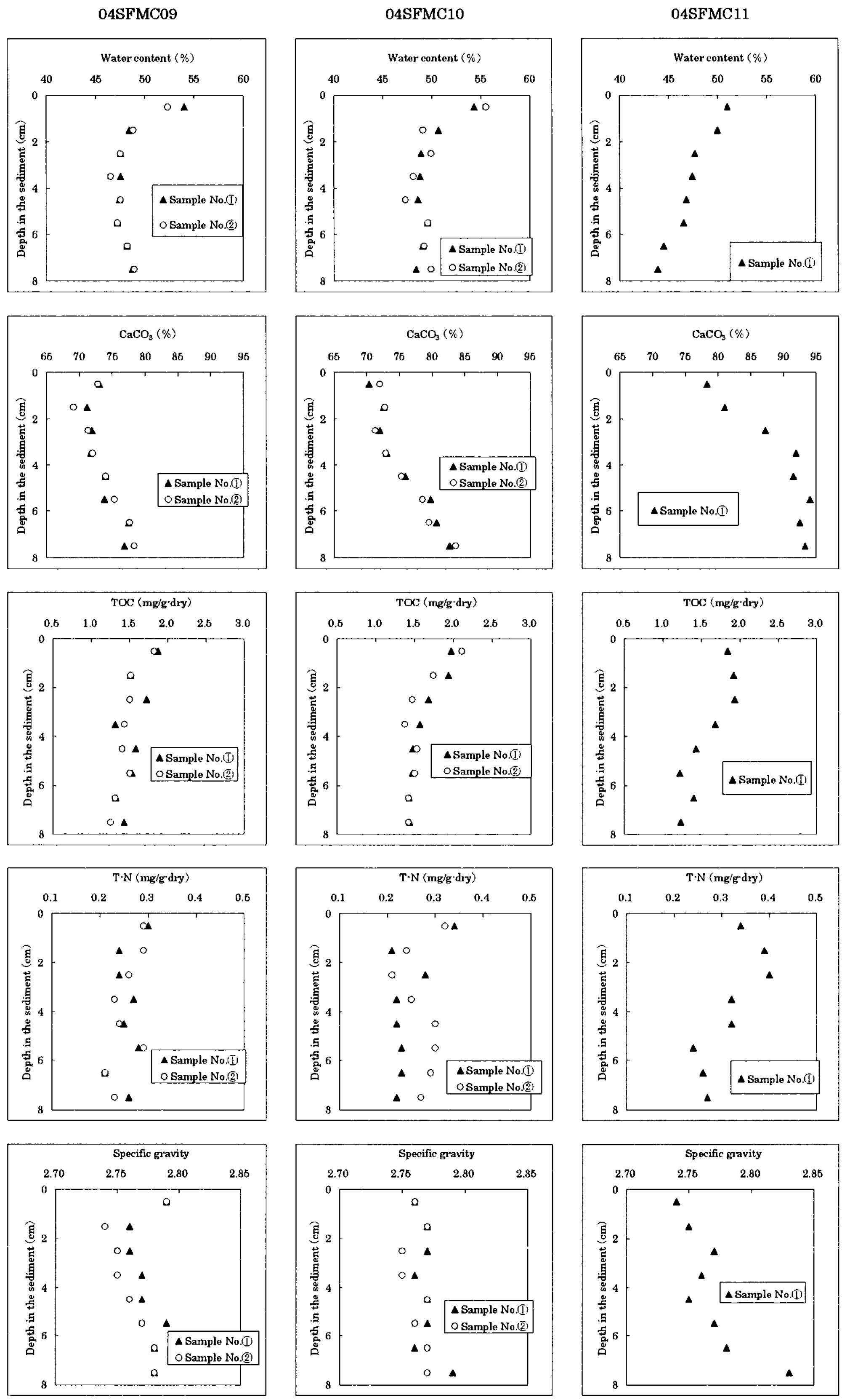


Figure 4 - 3 - 1 Vertical profiles of sediment properties

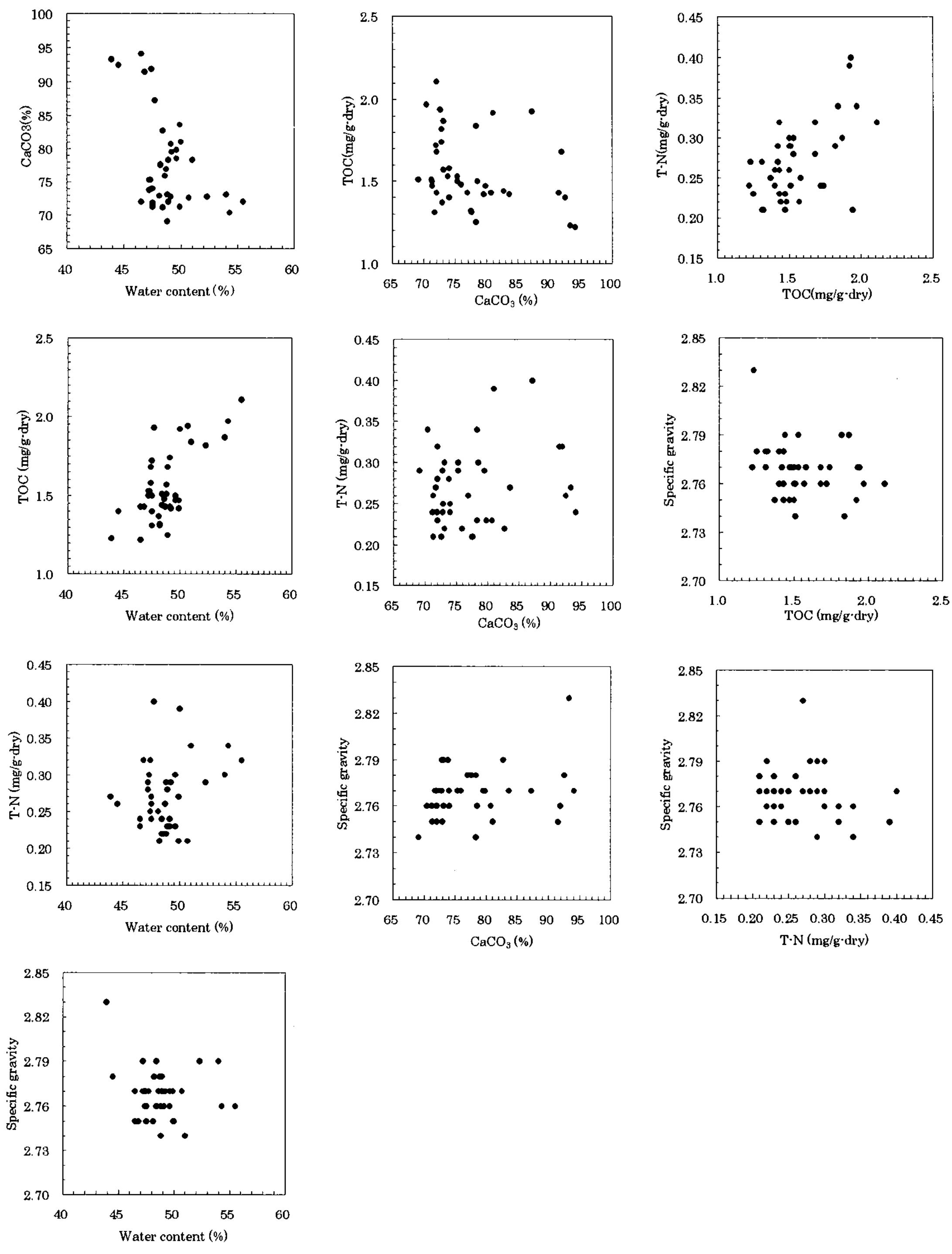


Figure 4 - 3 - 2 Relationship among sediment properties

4-3-2 Benthic Organisms

(1) Sedimentary Bacteria

The vertical distributions of abundances on sedimentary bacteria at each station were shown in Figure 4-3-3 and Table 3. At 04SFMC09, the highest abundance was 1.84×10^8 cells/g-dry on average in the 0-1 cm layer, and in layers deeper than 1 cm, the abundances were between 2.25×10^7 and 6.78×10^7 cells/g-dry on average. At 04SFMC10, the highest abundance was 1.02×10^8 cells/g-dry on average in the 0-1 cm layer, and the abundances decreased in 0-1 cm and 4-5 cm layers, and increased slightly in the 5-6 cm layer. At 04SFMC11, the highest abundance was 2.74×10^8 cells/g-dry in the 0-1 cm layer, and increased in 5-6 cm layer similarly to 04SFMC10.

At all stations, there were the highest abundances in the 0-1 cm layer, and showed a slight increase in the 5-6 cm layer. The abundances were higher in all the layers at 04SFMC11 than those of the other two stations.

(2) Meiobenthos

Eleven taxa were identified in the meiobenthos samples, including the phyla Protozoa (Foraminiferida), Nematoda (two taxa), Kinorhyncha, Loricifera, Tradigrada, Annelidia (Polychaeta) and Arthropoda (Ostracoda, Harpacticoida, Copepoda, and Nauplius larva) (Table 4-3-2). Foraminiferida, Nematoda, Harpacticoida and Nauplius larva were found at all the stations.

The average of the total meiobenthos abundances were 381.6 inds./10 cm^2 at 04SFMC09, 282.6 inds./10 cm^2 at 04SFMC10, and 580.6 inds./10 cm^2 at 04SFMC11; 04SFMC11 gave a higher number than the other two stations (Figure 4-3-4). Nematoda accounted for at least 64% at all stations, and 78% at 04SFMC11. Foraminiferida accounted for at least 18% at all the stations.

The vertical distributions at 04SFMC09 and 04SFMC10 indicated that the number of meiobenthos was highest in the 0-1 cm layer, and accounted for at least 64% (Figure 4-3-5). At 04SFMC11, many meiobenthos were found at depths of 0-1 cm, 1-2 cm, and 4-5 cm, and accounted for 38%, 18%, and 17% respectively at those depths.

Meiobenthos abundances correlated with water content, total organic carbon, and total nitrogen, and the correlation coefficients were 0.68, 0.65, and 0.50 respectively (Figure 4-3-6, Table 4-3-3). Meiobenthos did not correlate with calcium carbonate and specific gravity.

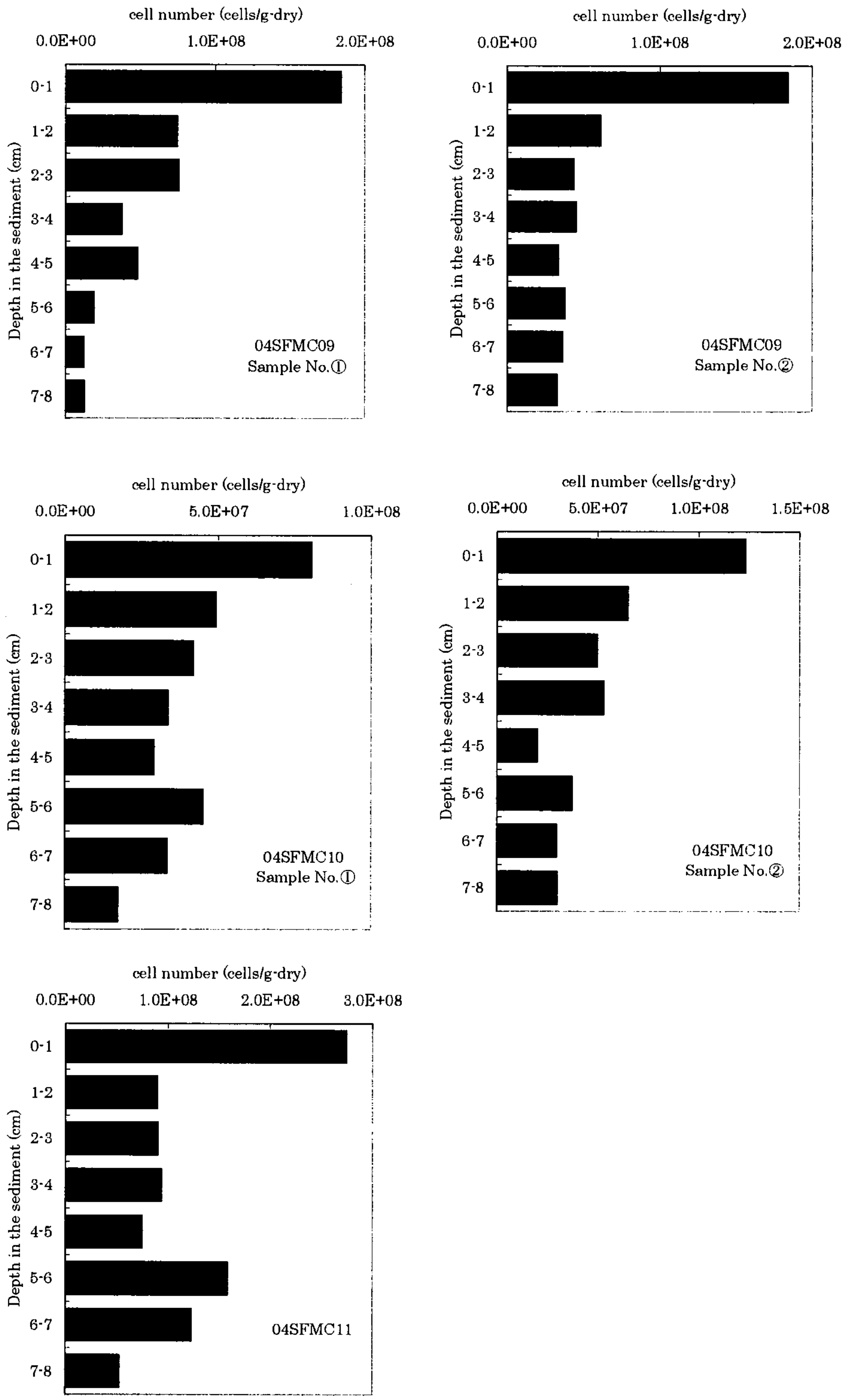


Figure 4 - 3 - 3 Vertical profiles of sedimentary bacteria

Table 4 - 3 - 2 Species and abundance of meiobenthos at each station

unit: inds./10cm³

No.	Taxa	04SFMC09 ① (cm) 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	total
1	Foraminiferida	76.7	9.0	6.8	6.8	4.5				103.8
2	NEMATODA	180.6	49.7	15.8	11.3	22.6	11.3		2.3	293.6
3	NEMATODA (Desmoscolecidae)	13.5								13.5
4	KINORHYNCHA	2.3								2.3
5	LORICIFERA									0.0
6	TARDIGRADA									0.0
7	Polychaeta									0.0
8	Ostracoda	2.3								2.3
9	Harpacticoida	4.5								4.5
10	Copepoda									0.0
11	Nauplius	9.0								9.0
	total	288.9	58.7	22.6	18.1	27.1	11.3	0.0	2.3	429.0

No.	Taxa	04SFMC09 ② (cm) 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	total
1	Foraminiferida	72.2	2.3	9.0					2.3	85.8
2	NEMATODA	126.4	29.3	13.5	6.8	13.5	4.5	9.0	4.5	207.5
3	NEMATODA (Desmoscolecidae)	22.6								22.6
4	KINORHYNCHA	2.3								2.3
5	LORICIFERA									0.0
6	TARDIGRADA									0.0
7	Polychaeta	2.3								2.3
8	Ostracoda									0.0
9	Harpacticoida	6.8								6.8
10	Copepoda									0.0
11	Nauplius	6.8								6.8
	total	239.4	31.6	22.5	6.8	13.5	4.5	9.0	6.8	334.1

No.	Taxa	04SFMC10 ① (cm) 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	total
1	Foraminiferida	54.2	9.0					2.3	2.3	67.8
2	NEMATODA	103.8	40.6	13.5	4.5	2.3	4.5		2.3	171.5
3	NEMATODA (Desmoscolecidae)	6.8	2.3	2.3	2.3					13.7
4	KINORHYNCHA									0.0
5	LORICIFERA									0.0
6	TARDIGRADA									0.0
7	Polychaeta	2.3								2.3
8	Ostracoda	2.3								2.3
9	Harpacticoida	2.3								2.3
10	Copepoda	2.3								2.3
11	Nauplius	11.3	2.3							13.6
	total	185.3	54.2	15.8	6.8	2.3	4.5	2.3	4.6	275.8

No.	Taxa	04SFMC10 ② (cm) 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	total
1	Foraminiferida	70.0	9.0	6.8				2.3	2.3	90.4
2	NEMATODA	97.1	33.9	9.0	6.8	11.3	2.3	4.5	4.5	169.4
3	NEMATODA (Desmoscolecidae)	11.3	4.5		2.3					18.1
4	KINORHYNCHA									0.0
5	LORICIFERA									0.0
6	TARDIGRADA	2.3								2.3
7	Polychaeta									0.0
8	Ostracoda									0.0
9	Harpacticoida	4.5								4.5
10	Copepoda									0.0
11	Nauplius	2.3		2.3						4.6
	total	187.5	47.4	18.1	9.1	11.3	2.3	6.8	6.8	289.3

No.	Taxa	04SFMC11 (cm) 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	total
1	Foraminiferida	60.9	20.3	4.5	6.8	9.0	2.3	2.3		106.1
2	NEMATODA	117.4	81.3	18.1	45.1	88.0	42.9	27.1	2.3	422.2
3	NEMATODA (Desmoscolecidae)	22.6	2.3	2.3		2.3				29.5
4	KINORHYNCHA									0.0
5	LORICIFERA	2.3								2.3
6	TARDIGRADA						2.3			2.3
7	Polychaeta	2.3								2.3
8	Ostracoda	2.3								2.3
9	Harpacticoida	6.8	2.3							9.1
10	Copepoda									0.0
11	Nauplius	4.5								4.5
	total	219.1	106.2	24.9	51.9	99.3	47.5	29.4	2.3	580.6

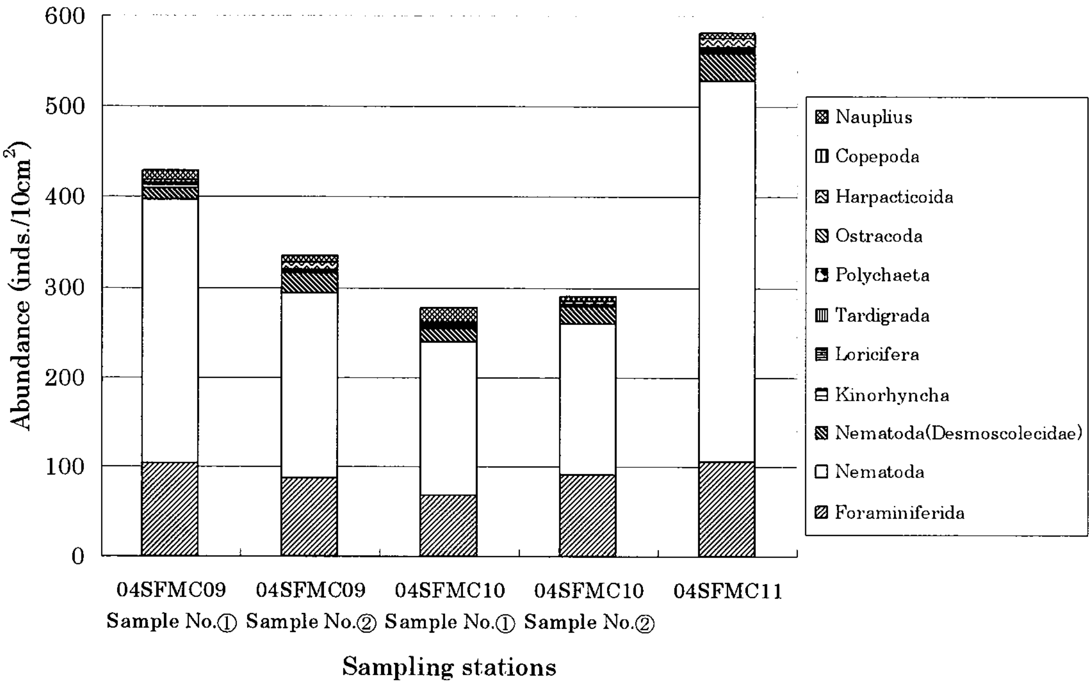


Figure 4‐3‐4 Abundances of meiobenthos at each station

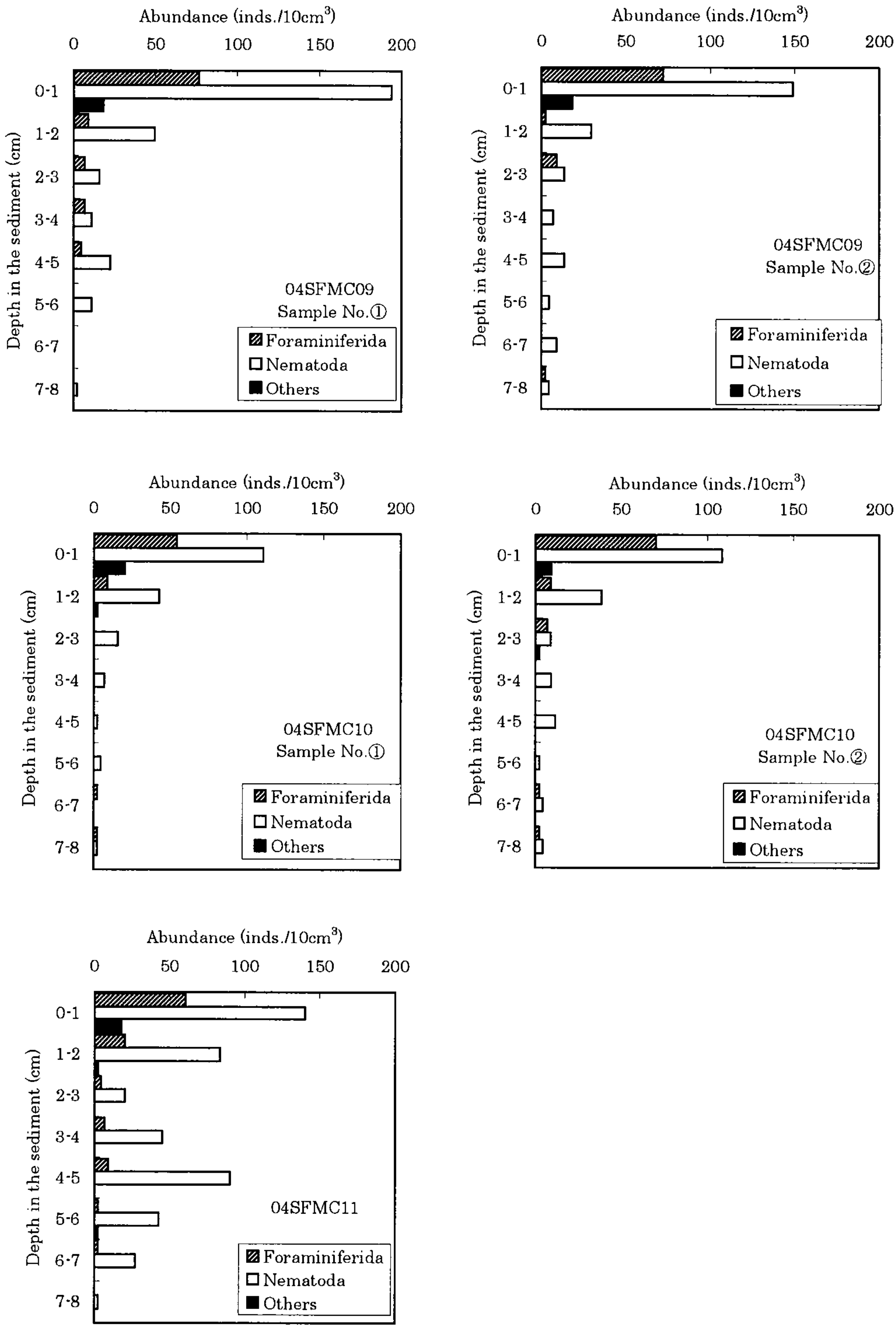


Figure 4 - 3 - 5 Vertical profiles of meiobenthos at each station

***Abundance of Nematoda in this figure is the sum of that of 「Nematoda」 and 「Nematoda (Desmoscolecidae)」 in Table 4-3-2**

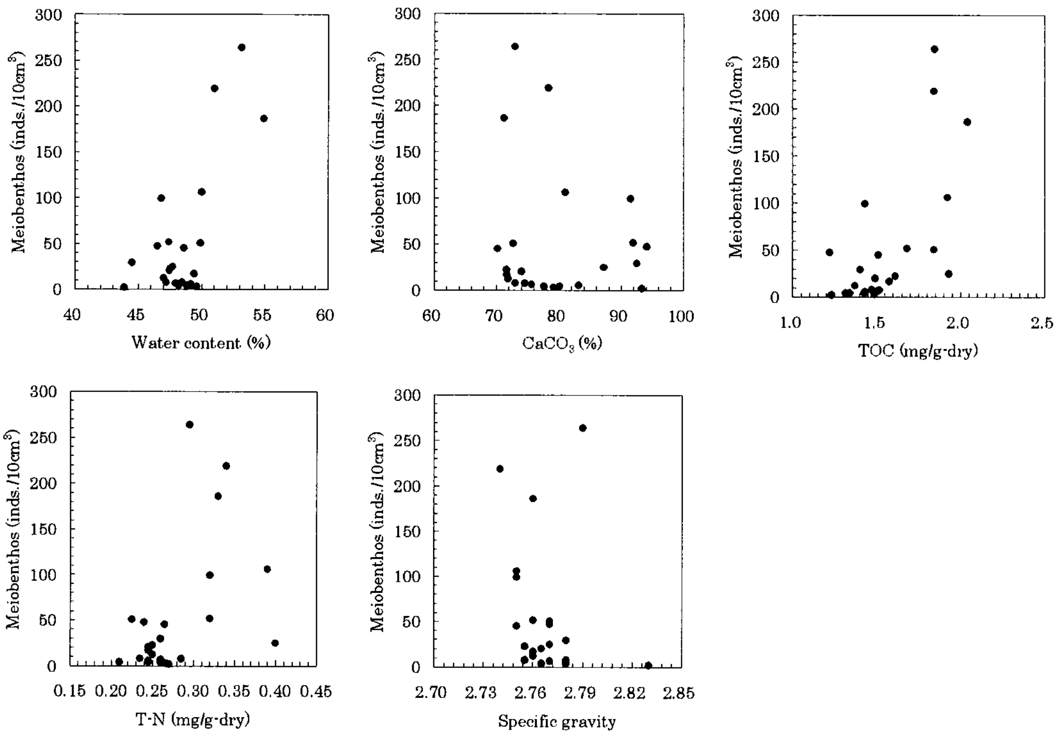


Figure 4 - 3 - 6 Correlation between meiobenthos and sediment properties

Table 4 - 3 - 3 Correlation matrix of meiobenthos abundance and sediment properties

Properties	Water content	$CaCO_3$	TOC	T-N	Specific gravity
Meiobenthos (inds./10cm^3)	0.68	-0.12	0.65	0.50	-0.22

(3) Macrobenthos

Macrobenthos organisms were obtained using FPG and AD, however, these surveys were not quantitative. Many macrobenthos were obtained using FPG, and few were obtained using AD (Table 4-3-4). Sixteen taxa were identified in the macrobenthos samples, including the phyla Porifera, Cnidaria (three taxa), Annelidia (three taxa) Vestimentifera, Mollusca (five taxa) and Arthropoda (three taxa). Figure 4-3-7 shows images of collected macrobenthos organisms. Vestimentifera and *Bathymodiolus* sp. were collected at 04SFFPG01, and Vestimentifera, *Calyptogena* sp. were collected at 04SFFPG03. These macrobenthos organisms which characterize chemotrophic community derived of hydrothermal deposits

Table 4 - 3 - 4 Species and abundance of macrobenthos for each sampling stations

sampling date : 25/12/04
N : number of individuals
Wet weight: gram
*、−: no count

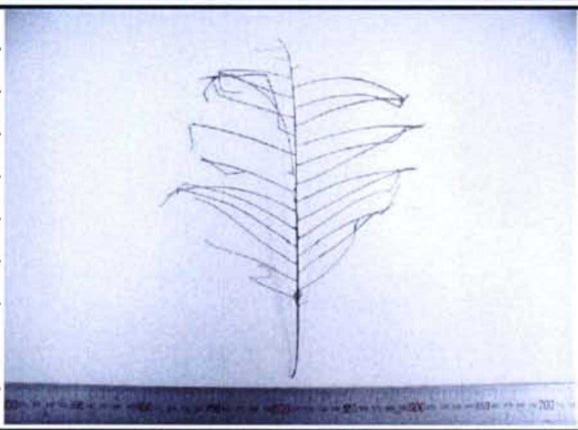
	Phylum	Class	Order	Family	Sta.	Central Hill								ERZA	
						04SFFPG01		04SFFPG02		04SFFPG03		04SFAD07		04SFAD05	
					Taxa	N	W.W.	N	W.W.	N	W.W.	N	W.W.	N	W.W.
1	PORIFERA	−	−	−	cf.PORIFERA					*	*				
2	CNIDARIA	HYDROZOA	Hydroida	Plumulariidae	Plumulariidae							1	2.23		
3		ANTHOZOA	Gorgonacea	−	Gorgonacea									*	7.65
4			Actiniaria	−	Actiniaria	2	4.39	2	1.10						
5	ANNELIDA	POLYCHAETA	Phyllodocida	Polynoidae	*Branchipolynoe pettiboneae*	2	0.69								
6				Nereididae	Nereididae	1	0.17								
7			Sabellida	Serpulidae	Serpulidae			3	0.24						
8	VESTIMENTIFERA	−	−	−	OBUTURATA	15	6.80			3	286.06				
9	MOLLUSCA	BIVALVIA	Solemyoida	Solemyidae	*Acharax johnsoni*			1	117.25	−	30.86				
10			Mytiloida	Mytilidae	*Bathymodiolus* sp.	117	1443.47								
11			Pterioida	Anomiidae	cf.Anomiidae			3	5.14						
12			Veneroida	Vesicomyidae	*Calyptogena* sp.					−	86.22				
13				Lucinidae	*Lucinoma* sp.					−	1148.48				
14	ARTHROPODA	CRUSTACEA	Thecostraca	Scalpellidae	Scalpellidae			102	53.81						
15				Balanidae	Balanidae	109	128.58								
16			Decapoda	Galatheidae	*Munidopsis* sp.	1	0.96								
					total inds. or W.W.	247	1585.06	111	177.54	3	1551.62	1	2.23	*	7.65
					total speacies	7		5		5		1		1	

Phylum	cf.PORIFERA

scale:1mm

Phylum	CNIDARIA
Class	HYDROZOA
Order	Hydroida
Family	Plumulariidae
	Plumulariidae

scale:1mm



Phylum	ANNELIDA
Class	POLYCHAETA
Order	Phyllodocida
Family	Polynoidae
	Branchipolynoe pettiboneae

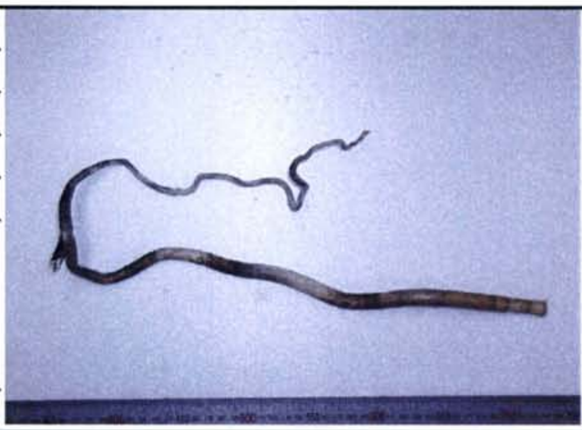
scale:1mm

Phylum	ANNELIDA
Class	POLYCHAETA
Order	Phyllodocida
Family	Nereididae
	Nereididae

scale:1mm

Figure 4 - 3 - 7 (1) Images of collected macrobenthos

Phylum	VESTIMENTIFERA (OBUTURATA)
	scale:1mm



Phylum	MOLLUSCA
Class	BIVALVIA
Order	Solemyoida
Family	Solemyidae
	Acharax johnsoni
	scale:1mm

Phylum	MOLLUSCA
Class	BIVALVIA
Order	Mytiloida
Family	Mytilidae
	Bathymodiolus sp.
	scale:1mm

Phylum	MOLLUSCA
Class	BIVALVIA
Order	Veneroida
Family	Vesicomyidae
	Calyptogena sp.
	scale:1mm

Figure 4 - 3 - 7 (2) Images of collected macrobenthos

Phylum	MOLLUSCA
Class	BIVALVIA
Order	Veneroida
Family	Lucinidae
	Lucinoma **sp.**
	scale:1mm

Phylum	ARTHROPODA
Class	CRUSTACEA
Order	Thecostraca
Family	Scalpellidae
	Scalpellidae
	scale:1mm

Phylum	ARTHROPODA
Class	CRUSTACEA
Order	Thecostraca
Family	Balanidae
	Balanidae
	scale:1mm

Phylum	ARTHROPODA
Class	CRUSTACEA
Order	Decapoda
Family	Galatheidae
	Munidopsis **sp.**
	scale:1mm

Figure 4 - 3 - 7 (3) Images of collected macrobenthos

4-3-3 Summary

Sediment properties were compared between the sampling stations. The vertical distribution of water content, calcium carbonate, organic carbon, total nitrogen and specific gravity at 04SFMC09 and 04SFMC10 were analogous. However, vertical distributions of these parameters differed at 04SFMC11. In particular, the concentrations of calcium carbonate were highest in the 5-6 cm layer compared with the other two stations. Calcium carbonate is deposited in the sediment as ejection of thermal water from the plumes progresses. The higher calcium carbonate content in the sediments of 04SFMC11 suggests hydrothermal deposits in this area.

The abundances of sedimentary bacteria and meiobenthos were also much higher in 04SFMC11 than 04SFMC09 or 04SFMC10.

The results of macrobenthos survey cannot be compared with the results from the sediment properties obtained from the sedimentary bacteria and the meiobenthos survey because the collection method and survey stations for the macrobenthos survey were different from those of the other subjects. However, analysis of the macrobenthos revealed a number of chemotrophic organisms, such as tube-dwelling worms (Vestimentifera) and bivalves (*Calyptogena* sp. etc.) at 04SFFPG01 and 04SFFPG03.

Comparing the correlations between the abundance of meiobenthos and each sediment properties, better correlation was observed with the organic carbon. This result could probably imply that the meiobenthos are utilizing organic carbon in the bottom sediment as food.

5. Conclusion

The environmental survey was carried out in designated areas as a baseline study to evaluate the magnitude of mining impacts on deep-sea environment. The survey was done to understand: 1) the water quality/ bacterioplankton survey and 2) the bottom sediment and benthic organism survey.

Results of the water quality and sedimentary bacteria survey, confirms the existence of an abnormal distribution of water temperature and bacteria in water depths greater than 1,600 m. This finding supports the possibility that hydrothermal plumes were present in these areas. In the survey of sediment properties and benthic organism, higher concentrations of calcium carbonate in 04SFMC11 than in 04SFMC09 and 04SFMC10 suggests that 04SFMC11 is affected by the hydrothermal deposits accumulated from the activity of thermal water. The presence of hydrothermal deposits is further supported by the observation of a number of chemotrophic macrobenthos, such as tube-dwelling worms and bivalves at 04SFFPG01 and 04SFFPG03.

Generally, these findings lead to a conclusion that effects of hydrothermal activity were recognized in the survey areas. Further investigation on the activities of manganese, methane and other chemical components as an indicator of hydrothermal activity, is suggested.

Appendix 1 Analytical results for bacterioplankton

Station	Sample No.	Depth (m)	Cell number (cells/ml)
04SFRO06	1	1910	1.16E+04
	2	1866	9.57E+03
	3	1837	1.15E+04
	4	1817	1.02E+04
	5	1787	9.55E+03
	6	1764	1.05E+04
	7	1739	1.28E+04
	8	1716	1.33E+04
	9	1662	1.31E+04
	10	1616	1.04E+04
	11	1415	1.10E+04
	12	914	1.86E+04
04SFRO07	1	1922	1.16E+04
	2	1878	1.23E+04
	3	1844	1.08E+04
	4	1830	1.14E+04
	5	1806	1.02E+04
	6	1782	1.03E+04
	7	1756	1.22E+04
	8	1732	1.40E+04
	9	1681	1.53E+04
	10	1631	1.39E+04
	11	1431	1.51E+04
	12	932	1.40E+04

Appendix 2 Analytical results for sediment properties

Station	Sample No.	Layer (cm)	Water content (%)	$CaCO_3$ (%)	TOC (mg/g·dry)	T·N (mg/g·dry)	T·S (mg/g·dry)	Specific gravity
04SFMC09	①	0-1	54.0	73.1	1.87	0.30	<0.01	2.79
		1-2	48.4	71.2	1.51	0.24	<0.01	2.76
		2-3	47.5	71.9	1.72	0.24	<0.01	2.76
		3-4	47.5	71.7	1.31	0.27	<0.01	2.77
		4-5	47.4	74.0	1.58	0.25	<0.01	2.77
		5-6	47.2	73.8	1.53	0.28	<0.01	2.79
		6-7	48.2	77.5	1.32	0.21	<0.01	2.78
		7-8	48.7	76.9	1.43	0.26	<0.01	2.78
	②	0-1	52.3	72.8	1.82	0.29	−	2.79
		1-2	48.8	69.1	1.51	0.29	−	2.74
		2-3	47.5	71.3	1.50	0.26	−	2.75
		3-4	46.5	72.0	1.43	0.23	−	2.75
		4-5	47.5	74.0	1.40	0.24	−	2.76
		5-6	47.2	75.3	1.50	0.29	−	2.77
		6-7	48.2	77.6	1.31	0.21	−	2.78
		7-8	48.9	78.3	1.25	0.23	−	2.78
04SFMC10	①	0-1	54.3	70.4	1.97	0.34	<0.01	2.76
		1-2	50.7	72.6	1.94	0.21	<0.01	2.77
		2-3	48.9	72.0	1.68	0.28	<0.01	2.77
		3-4	48.8	73.1	1.57	0.22	<0.01	2.76
		4-5	48.6	75.9	1.48	0.22	<0.01	2.77
		5-6	49.6	79.8	1.47	0.23	<0.01	2.77
		6-7	49.1	80.7	1.43	0.23	<0.01	2.76
		7-8	48.4	82.7	1.44	0.22	<0.01	2.79
	②	0-1	55.5	72.0	2.11	0.32	−	2.76
		1-2	49.1	72.8	1.74	0.24	−	2.77
		2-3	49.9	71.3	1.47	0.21	−	2.75
		3-4	48.1	72.9	1.37	0.25	−	2.75
		4-5	47.3	75.3	1.53	0.30	−	2.77
		5-6	49.6	78.5	1.50	0.30	−	2.76
		6-7	49.2	79.5	1.42	0.29	−	2.77
		7-8	49.9	83.6	1.42	0.27	−	2.77
04SFMC11	①	0-1	51.0	78.3	1.84	0.34	<0.01	2.74
		1-2	50.0	81.0	1.92	0.39	<0.01	2.75
		2-3	47.7	87.2	1.93	0.40	<0.01	2.77
		3-4	47.4	91.9	1.68	0.32	<0.01	2.76
		4-5	46.8	91.5	1.43	0.32	<0.01	2.75
		5-6	46.5	94.1	1.22	0.24	<0.01	2.77
		6-7	44.5	92.5	1.40	0.26	<0.01	2.78
		7-8	43.9	93.3	1.23	0.27	<0.01	2.83

Appendix 3 Analytical results for sedimentary bacteria

Station	Sample No.	Layer (cm)	Cell number (cells/g-dry)
04SFMC09	①	0-1	1.84E+08
		1-2	7.43E+07
		2-3	7.53E+07
		3-4	3.75E+07
		4-5	4.78E+07
		5-6	1.89E+07
		6-7	1.20E+07
		7-8	1.25E+07
	②	0-1	1.84E+08
		1-2	6.14E+07
		2-3	4.36E+07
		3-4	4.52E+07
		4-5	3.35E+07
		5-6	3.78E+07
		6-7	3.61E+07
		7-8	3.26E+07
04SFMC10	①	0-1	8.04E+07
		1-2	4.92E+07
		2-3	4.17E+07
		3-4	3.35E+07
		4-5	2.90E+07
		5-6	4.51E+07
		6-7	3.32E+07
		7-8	1.71E+07
	②	0-1	1.23E+08
		1-2	6.47E+07
		2-3	4.94E+07
		3-4	5.29E+07
		4-5	2.00E+07
		5-6	3.72E+07
		6-7	2.94E+07
		7-8	2.96E+07
04SFMC11	①	0-1	2.74E+08
		1-2	8.91E+07
		2-3	8.98E+07
		3-4	9.35E+07
		4-5	7.47E+07
		5-6	1.58E+08
		6-7	1.23E+08
		7-8	5.23E+07