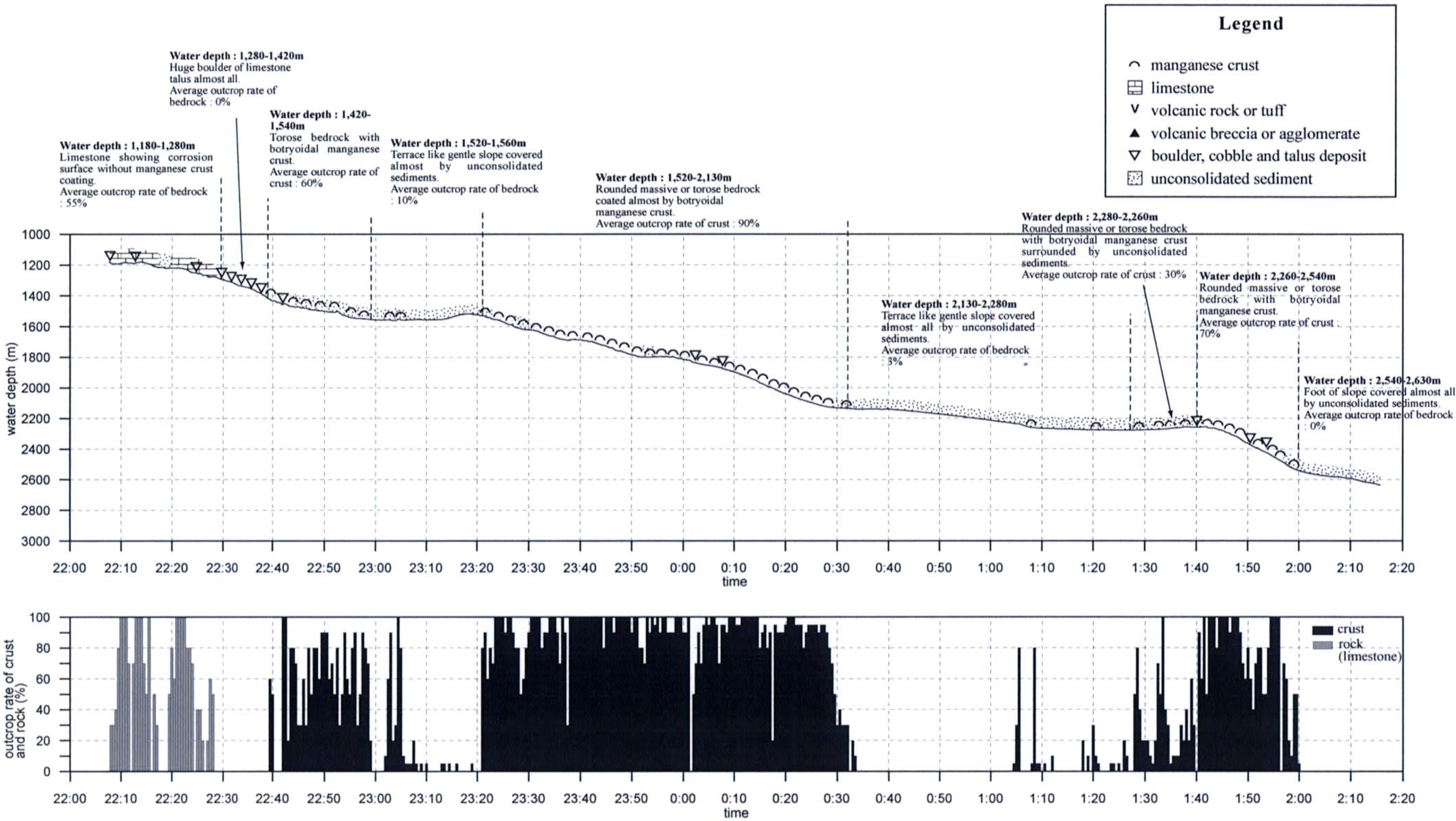
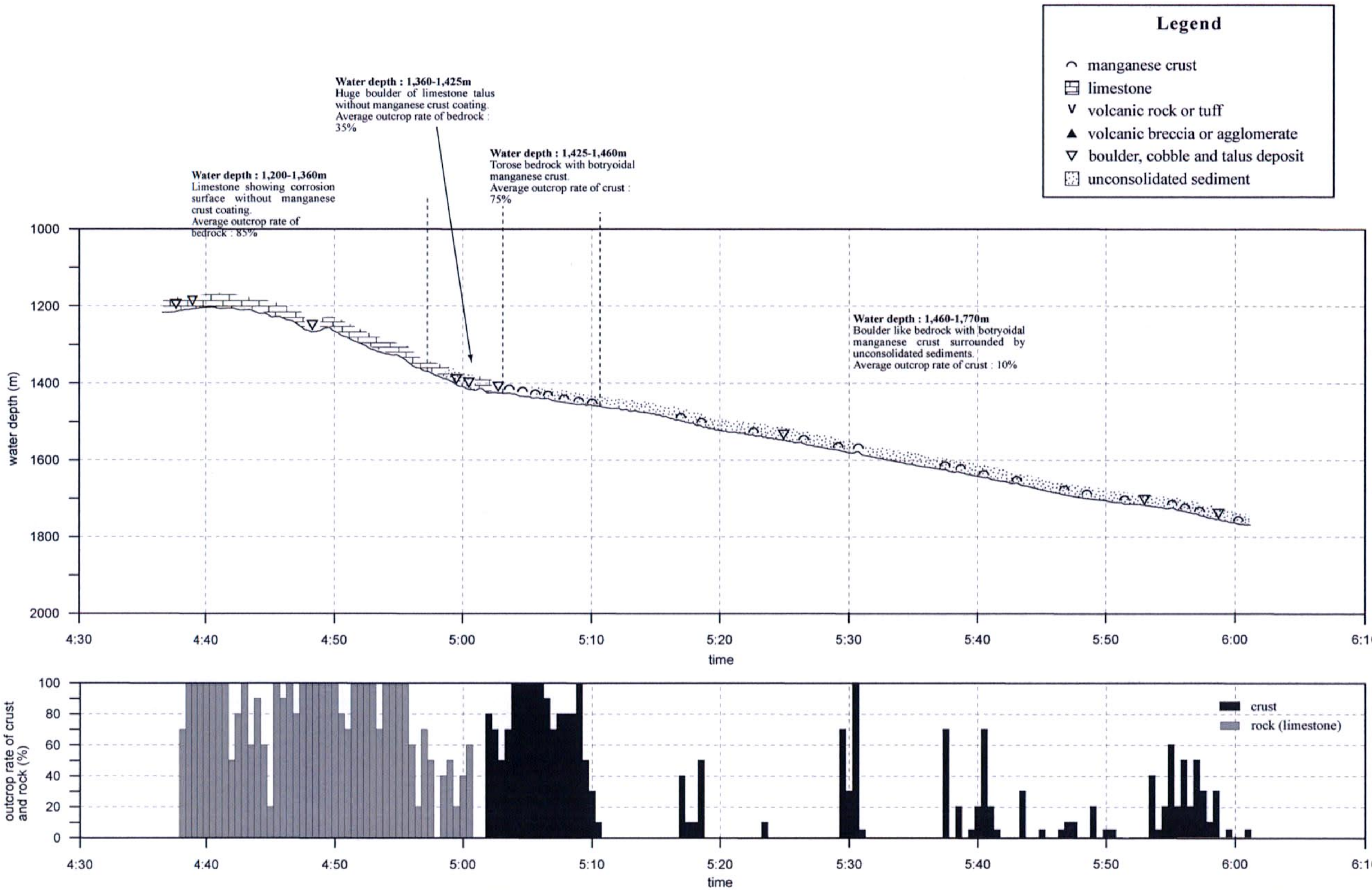
Appendix 4

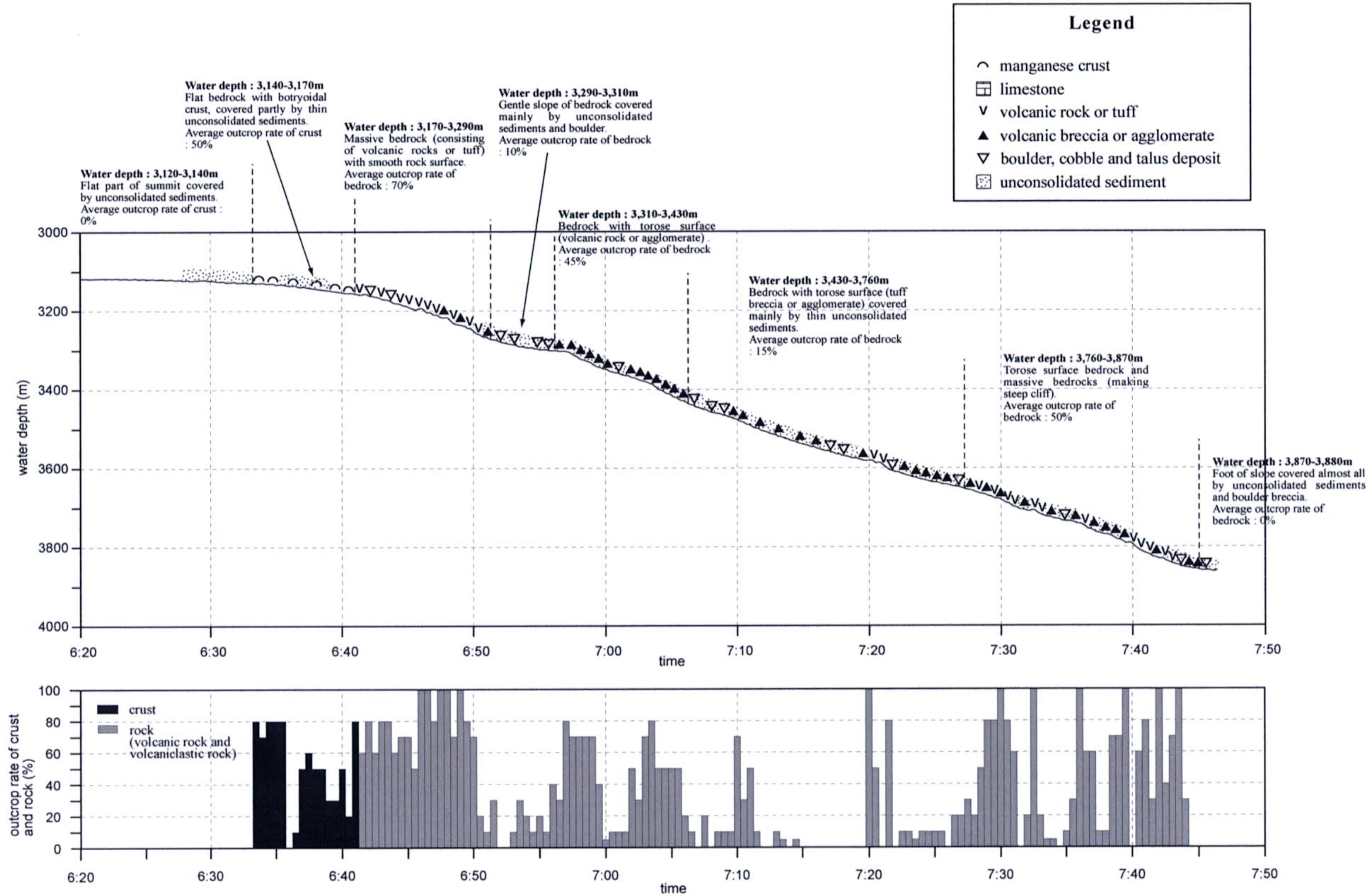
Topographic Profile of FDC Lines



Appendix Fig. 4-1 Cross section of FDC observation and exposed rate diagram of manganese crusts (05SMC12FDC02)



Appendix Fig. 4-2 Cross section of FDC observation and exposed rate diagram of manganese crusts (05SMC12FDC03)



Appendix Fig. 4-3 Cross section of FDC observation and exposed rate diagram of manganese crusts (05SMC13FDC02)

Appendix 5 Laboratory Work

5-1 Microscopic Observation of Rock Samples

5-1-1 Samples

Thin sections were prepared for six samples as shown in Table 5-1-1. Descriptions of hand specimens and thin section were conducted by Katsuhiko Maeda, a geologist of Mitsubishi Materials Natural Resources Corp.

Table 5-1-1 Rock Samples for Microscopic Observation

Serial No.	Sample No.	Depth of Bottom Touch (m)	Individual Piece No. of Samples	Rock Name	Remarks
1	05SMC12AD16_TS01	2,004	c2	aphyric basalt	–
2	05SMC12AD19_TS01	1,873	c1	aphyric basalt	–
3	05SMC12AD27_TS01	2,209	c3	basalt cobble of calcareous conglomerate	–
4	05SMC12AD29_TS01	2,385	c6	aphyric basalt	–
5	05SMC13AD15_TS01	1,724	-	materials filling interstices	agate ?
6	05SMC13AD16_TS01	2,061	c1	clinopyroxene basalt	–

5-1-2 Descriptions of Hand Specimen

Prior to preparation of thin sections, all hand specimens were described. The photographs of hand specimen are given in Plate I. The descriptions of each sample are given below.

05SMC12AD16 TS01

It is brownish dark gray, aphyric basalt and it shows intensive vesicularity with abundant vesicles of 2-3mm across. The vesicles are filled and coated by milky white to brown calcite and limonite. Cracks are occasionally filled by calcite veins of 1-2mm wide.

05SMC12AD19 TS01

It is brownish dark gray aphyric basalt, and vesicles of 0-3mm across occur showing vermicular texture. Vesicles are filled and coated by limonite. Brownish milky white calcite rarely occurs filling the vesicles.

05SMC12AD27 TS01

It is dark gray aphyric basalt with abundant vesicles. The vesicles are 2-3cm across and the amount of vesicles reaches to 40 volume% of whole rock. Limonite and carbonate occasionally occur attached on the inner surface of vesicles.

05SMC12AD29 TS01

It is brown to dark gray, aphyric basalt and these colors changes gradationally. Vesicularity is poor and the vesicles filled by limonite usually show globular shape of 1-2cm across. Slightly large vesicles of 3mm across rarely occur. Angular fragments of pale brownish gray to milky white quartz and calcite, 3-4mm across, are included.

05SMC13AD15 TS01

It is colorless to reddish dark gray agate. In its inner part, it shows reddish dark gray, parallel, fibrous stripes of 3mm interval. Less than 5mm thick fragment of limestone is partly attached on the surface.

05SMC13AD16 TS01

It is dark gray, pyroxene basalt with clinopyroxene and hyperthene phenocrysts of less than 0.5mm across. Rarely altered hornblende of less than 0.5mm across is observed. It is generally compact, but rarely less than 0.5mm across vesicles filled by milky white calcite and limonite are observed. It includes 3mm across, angular xenolith.

5-1-3 Microscopic Observation of Thin Sections

The results of microscopic observations are given in Table 5-1-2, and description sheet and micrographs are shown on Plate II.

Table 5-1-2 Results of Microscopic Observation

Sea Mountain	Sample No.	Depth (m)	Individual Piece No. of Samples	Rock Name	Texture	Alteration	Phenocrysts								Groundmass							Secondary Minerals							
							Q	Pl	Cpx	Opx	Ol	Hb	Bi	Op	Q	Pl	Cpx	Hb	Ol	Op	G	Chl	Sm	Pal	Cb	Cc	Q	Cly	Others
MC12	05SMC12AD16 TS01	2004	c2	Basalt	intersertal vesicular	Intermediate		○						○		◎					△					△			Limonite (○) 、Hematite (△)
	05SMC12AD19 TS01	1873	c1	Basalt	intersertal vesicular	Intermediate		○						○		◎					△								Limonite (○) 、Hematite (△)
	05SMC12AD27 TS01	2209	c3	Apyric Basalt	aphyricvesicular	Weak		△						△		◎					○								Hematite (△)
	05SMC12AD29 TS01	2385	c6	Basalt	intersertal vesicular	Strong		△						△		◎										△			Goethite (△) 、Limonite (◎)
MC13	05SMC13AD15 TS01	1724	–	Agate	aphanitic	–																					◎		
	05SMC13AD16 TS01	2061	c1	Clinopyroxene Basalt	intersertal vesicular	Intermediate		△	△							△													Limonite (○) 、Goethite (△)

Q ; Quartz
Pl ; Plagioclase
Cpx ; Clinopyroxene
Opx ; Orthpyroxene
Ol ; Olivine
Hb ; Hornblende
Bi ; Biotite
Op ; Opaque minerals
G ; Glass

Chl ; Chlorite
Sm ; Smectite
Ep ; Epidote
Pal ; Paragonite
Cb ; Cristobarite
Cc ; Calcite
Cly ; Clay Minerals
Ne ; Nepheline

* ; Pseudomorph

◎ ; abundant (>30)
○ ; Common (10~30)
△ ; Rare (3~10)
・ ; Trace (<3)

5-2 Chemical Analyses of Igneous Rock

5-2-1 Samples

The chemical analyses of volcanic rocks were conducted for six samples They are four from MC12 area, one from MC13 area and one standard sample of JB-3, which is standard sample of basalt prepared by JGS (Table5-2-1).

Table 5-2-1 Rock Samples of Chemical Analysis

Serial No.	Sea Mt.	Sample No.	Depth of Bottom Touch (m)	Individual Piece No. of Samples	Rock Name
1	MC12	05SMC12AD16_CA01	2,004	c2	aphyric basalt
2		05SMC12AD19_CA01	1,873	c1	aphyric basalt
3		05SMC12AD27_CA01	2,209	c3	basalt cobble of calcareous conglomerate
4		05SMC12AD29_CA01	2,385	c6	aphyric Basalt
5	MC13	05SMC13AD16_TS01	2,061	c1	clinopyroxene basalt
6	—	JB-3	—	—	basalt

5-2-2 Chemical Analyses

As given below, chemical analyses of 44 elements were conducted.

Major elements (16 elements)

SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, Cr_2O_3、 CO_2, H_2O^+, $H2O^-$, LOI (detection limit: 0.01%)

Trace elements (28 elements)

Rb, Ba, Zr, Y, Cs, Ta, U (detection limit: 0.1ppm)

Sr, V, Nb, Hf, Pb, Th, Ni (detection limit: 1ppm)

REE (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu) (detection limit 0.01ppm)

5-2-3 Analytical Methods

After drying samples for more than 12 hours using dry oven, samples were crushed by hand using iron pot. Samples were dried again for more than 12 hours, then, pulverized to 250 micron size by tungsten carbide mill.

Chemical analyses were conducted at ALS Chemex, Canada. Since all the samples were collected in the ocean, desalination was conducted for all the samples. For chemical analyses of major elements and trace elements other than Zr, Ba and REE, samples were digested using HF-HNO_3-$HClO_4$ acid. Lithium borate fusion was conducted for chemical analyses of Zr, Ba and REE. The chemical analyses of major element (SiO_2、 TiO_2、 Al_2O_3、 Fe_2O_3、 MnO、 MgO、 CaO、 Na_2O、 K_2O、 P_2O_5、 Cr_2O_3、 LOI) were conducted by X-ray Fluorescence Analysis (Panalytical (former Philips), PW2404 XRF). FeO was determined by titration. Trace elements, such as Rb、Ba、Zr、Y、Cs、Ta、U、Sr、V、Nb、Hf、Pb、Th、Ni、REE (La、Ce、Pr、Nd、Sm、Eu、Gd、Tb、Dy、Ho、Er、Tm、Yb、Lu) , were analyzed by Inductively Coupled Plasma –Mass Spectrometry (Perkin Elmer, Elan9000 ICP-MS). LECO (LECO, RMC-100) was used for determination of CO_2、 $H2O^+$、 $H2O^-$.

5-2-4 Analytical Results

The analytical results are given in Table 5-2-2.

The analytical results of standard samples prepared by ALS Chemex, which were simultaneously analyzed together with the samples of MC12 and MC13 areas, were shown in Table5-2-3.

All the samples show high LOI, ranging from 2.43% to 5.96%, and among them MC13 sample has the lowest LOI of 2.43%. Fe_2O_3 is high compared with FeO in all the samples, and P_2O_5, ranging from 0.52% to 4.67%, is very high compared to common igneous rock value of less than 0.5%. Coincide with the results of microscopic observation, these high values of LOI, Fe_2O_3 and P_2O_5 suggest considerable alteration of these rocks, characterized by occurrences of secondary minerals such as clay minerals and phosphate minerals. In addition, relatively high CO_2 values of 0.55% to 1.28% suggest occurrences of carbonates as secondary minerals. 05SMC13AD16 shows the major elements chemistry of the least alteration compared with other samples of MC12.

Reflecting these alterations, SiO_2, ranging from 44.75% to 48.98%, is low compared with normal basaltic rock. MgO varies from 0.70% to 2.71% for the samples of MC12 and a wide range of Mg#, 10.34 to 31.64, was obtained. The highest MgO, 4.17%, and the highest Mg#, 35.41, was obtained from the samples of MC13. The sample of MC13 shows slightly different nature compared with five samples of MC12. The former shows higher TiO_2, MgO, CaO and lower Al_2O_3, NaO and K_2O compared with the latter.

Table 5-2-2 Analytical Results of Volcanic Rocks

Sample No.		05SMC12AD16 CA01	05SMC12AD19 CA01	05SMC12AD27 CA01	05SMC12AD29 CA01	05SMC13AD16 CA01	Standard Sample JB-3	Standard Sample JB-3 Recommended Value
Rock Name		Aphyric Basalt	Aphyric Basalt	Apyric Basalt	Apyric basalt	Clinopyroxene Basalt	Basalt	Basalt
Rock Type		alkali	alkali	alkali	alkali	sub-alkali	High Alumina Basalt	High Alumina Basalt
wt %	SiO2	45.96	44.76	44.75	48.98	45.94	50.08	50.96
	TiO2	2.75	2.86	2.31	1.73	2.96	1.53	1.44
	Al2O3	16.70	17.65	16.66	18.07	14.35	17.25	17.20
	Fe2O3	10.16	10.37	7.14	7.29	9.41	4.52	3.20
	FeO	1.29	1.48	1.22	1.22	5.08	6.18	7.85
	MnO	0.06	0.10	0.09	0.09	0.20	0.16	0.18
	MgO	2.71	0.70	1.41	1.29	4.17	4.31	5.19
	CaO	5.91	8.18	10.35	7.02	10.66	8.98	9.79
	Na2O	3.25	3.48	3.56	4.42	2.56	2.90	2.73
	K2O	3.01	3.36	2.79	2.79	0.98	1.40	0.78
	P2O5	1.89	3.27	4.67	1.84	0.52	0.74	0.29
	Cr2O3	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.17
	CO2	1.28	0.66	0.77	0.66	0.55	0.07	0.44
	H2O+	2.17	1.67	1.50	1.48	1.34	0.67	0.18
	H2O-	3.55	1.24	2.38	2.57	1.86	0.62	0.07
	LOI	5.96	3.30	4.21	4.78	2.43	1.06	–
	TOTAL	99.65	99.51	99.16	99.52	99.27	99.12	–
FeO* (*1)		10.43	10.81	7.65	7.78	13.55	10.25	10.73
Mg# (*2)		31.64	10.34	24.72	22.79	35.41	42.83	46.29
ppm	Rb	192.0	42.4	97.7	71.2	29.2	33.1	15.1
	Ba	309.0	347.0	495.0	395.0	50.4	281.0	245.0
	Zr	452.0	434.0	433.0	579.0	205.0	260.0	97.8
	Y	48.0	60.6	114.5	51.4	52.0	33.7	26.9
	Cs	20.3	0.6	7.9	4.8	2.3	2.2	0.9
	Ta	5.0	5.4	5.2	6.3	0.8	2.0	0.2
	U	1.4	1.7	2.0	1.8	0.4	0.9	0.5
	Sr	673	725	856	728	254	473	403
	V	127	239	87	50	419	287	372
	Nb	77	79	79	98	12	31	2
	Hf	12.0	12.0	11.0	16.0	6.0	7.0	2.7
	Pb	4.0	6.4	4.2	4.0	1.8	5.9	5.6
	Th	6.0	7.0	6.0	9.0	1.0	4.0	1.3
	Ni	16.0	29.0	12.0	17.0	38.0	36.0	36.2
	La	60.60	69.20	123.50	77.40	15.00	28.60	8.81
	Ce	133.50	142.50	142.50	162.50	37.70	68.50	21.50
	Pr	17.00	17.90	22.60	19.80	5.10	8.00	3.11
	Nd	70.20	73.60	91.30	79.90	24.10	33.90	15.60
	Sm	14.80	16.00	17.80	14.80	7.20	7.50	4.27
	Eu	4.60	5.10	5.80	4.60	2.70	2.30	1.32
	Gd	13.20	15.60	19.20	13.80	8.40	7.40	4.67
	Tb	1.90	2.20	2.70	2.00	1.50	1.20	0.73
	Dy	10.40	12.00	14.60	10.20	9.90	6.50	4.54
	Ho	1.70	2.10	2.90	1.90	2.00	1.30	0.80
	Er	4.70	5.90	8.20	5.10	5.70	3.40	2.49
	Tm	0.60	0.70	1.00	0.70	0.90	0.50	0.42
	Yb	3.50	4.30	6.20	4.10	5.20	3.10	2.55
	Lu	0.50	0.70	1.00	0.60	0.90	0.50	0.39

*1 $FeO^* = FeO + (0.9*Fe_2O_3)$

*2 $Mg\# = 100*Mg/(Mg+Fe^{2+})$

Table 5-2-3 Analytical Results of ALS Chemex Standard Samples

Standard Samples		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI
		%										
STSD-2 (Standard)	Results of This Time	53.79	0.80	16.07	7.48	0.14	3.19	4.01	1.76	2.19	0.33	9.87
STSD-2 Recommended Value	Lower Bound	*51.01*	*0.74*	*15.29*	*7.12*	*0.12*	*2.94*	*3.79*	*1.65*	*2.00*	*0.29*	*9.78*
	Upper Bound	*56.40*	*0.84*	*16.92*	*7.90*	*0.16*	*3.28*	*4.21*	*1.85*	*2.24*	*0.35*	*10.83*

Standard Samples		FeO
		%
SY-4 (Standard)	Results of This Time	2.83
SY-4 Recommended Value	Lower Bound	*2.78*
	Upper Bound	*2.94*

Standard Samples		Rb	Ba	Zr	Y	Cs	Ta	U**	Sr	V**	Nb	Hf	Pb**	Th	Ni
		ppm													
SY-4 (Standard)	Results of This Time	57.7	326	530	126	1.7	0.9	3.6	1215	110	14	12	703	2	11
SY-4 Recommended Value	Lower Bound	*49.3*	*306*	*465*	*107*	*1.3*	*<0.5*	*2.9*	*1070*	*96*	*11*	*9*	*603*	*<1*	*<5*
	Upper Bound	*60.7*	*375*	*569*	*132*	*1.8*	*1*	*3.7*	*1310*	*120*	*15*	*13*	*738*	*2*	*10*

Standard Samples		La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
		ppm													
SY-4 (Standard)	Results of This Time	60.6	127	15.8	61.5	12.4	2	14.4	2.8	18.5	4.5	14.7	2.4	15.3	2.3
SY-4 Recommended Value	Lower Bound	*51.7*	*110*	*13.4*	*50.8*	*11.3*	*1.7*	*12.5*	*2.2*	*16.3*	*3.8*	*12.7*	*2*	*13.2*	*1.8*
	Upper Bound	*64.3*	*135*	*16.6*	*63.2*	*14.1*	*2.3*	*15.5*	*3*	*20.1*	*4.8*	*15.7*	*2.6*	*16.4*	*2.4*

Standard Samples		C
		%
B-03 (Standard)	Results of This Time	0.02
B-03 Recommended Value	Lower Bound	*<0.01*
	Upper Bound	*0.02*

Standard Samples		H2O+	H2O-
		%	
G-2000 (Standard)	Results of This Time	3.19	0.81
G-2000 Recommended Value	Lower Bound	*2.89*	*0.70*
	Upper Bound	*3.35*	*0.82*

* ALS Chemex LTD.

** Standard sample G2000 was used.

5-2-5 Considerations

(1) Chemical Nature of the Samples

To understand the nature of the major elements chemistry, the analytical results were plotted on alkali-Silica Diagram (Figure5-2-1), TAS (total alkalis-silica) Diagram (Fig.5-2-2) and AFM (Na_2O+K_2O-FeO^{total}-MgO) Diagram (Figure 5-2-3).

The results of microscopic observation and chemical analyses suggest considerable alteration of these rocks. Consequently these diagrams of major elements do not precisely show original nature of the igneous rocks. On the alkali-silica diagram, all the samples of MC12 are plotted in the field of alkali rock, while the sample of MC13 (05SMC13AD16CA01) is plotted in subalkalic field. Further, on the TAS diagram, all the samples of MC12 are distributed in and around tephrite field and the sample of MC13 is plotted in basalt filed. Although SiO_2 values of the all the rock may have been decreased by alteration, the sample of MC13 seems to have slightly different chemical nature from all other samples of MC12. All the samples are plotted in the filed of tholeiite trend on the AFM diagram.

For considering the petrogenetic setting of these rock, MORB normalized spiderdiagram and chondorite normalized REE patterns are constructed (Figures 5-2-4 and 5-2-5). The chemical compositions of MORB and chodrite used for normalization were after Sun et al. (1997) and Wakita et al. (1971), respectively (Table5-2-4).

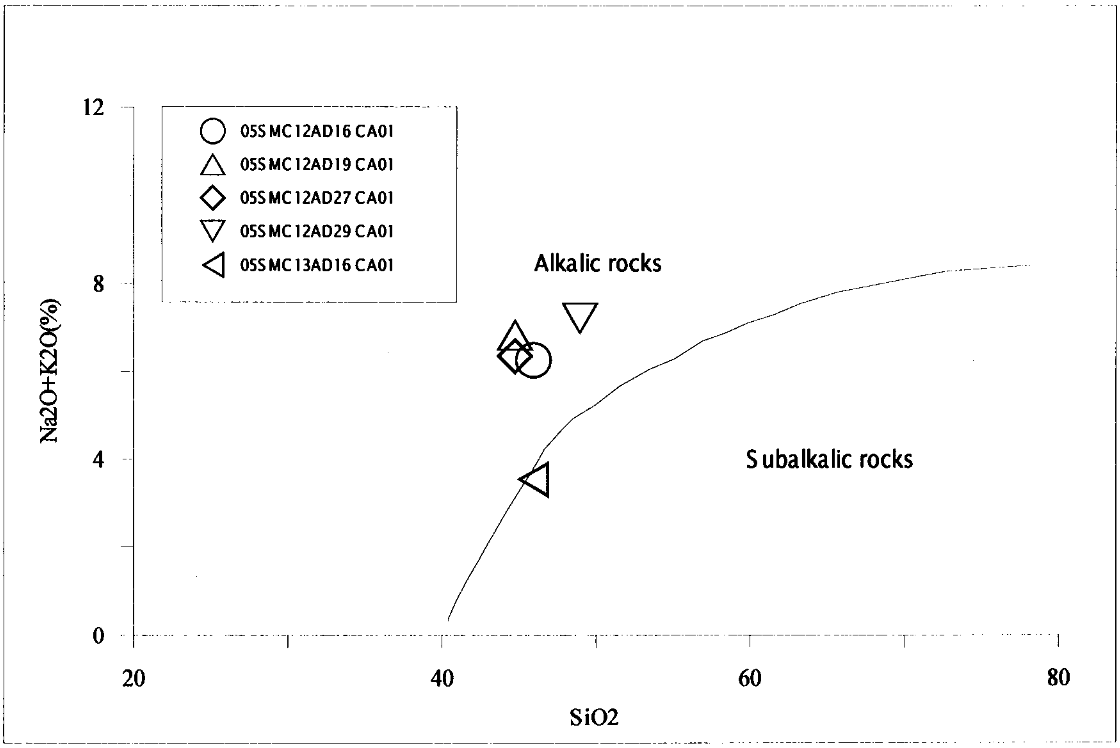


Figure 5-2-1 Alkali-Silica Diagram

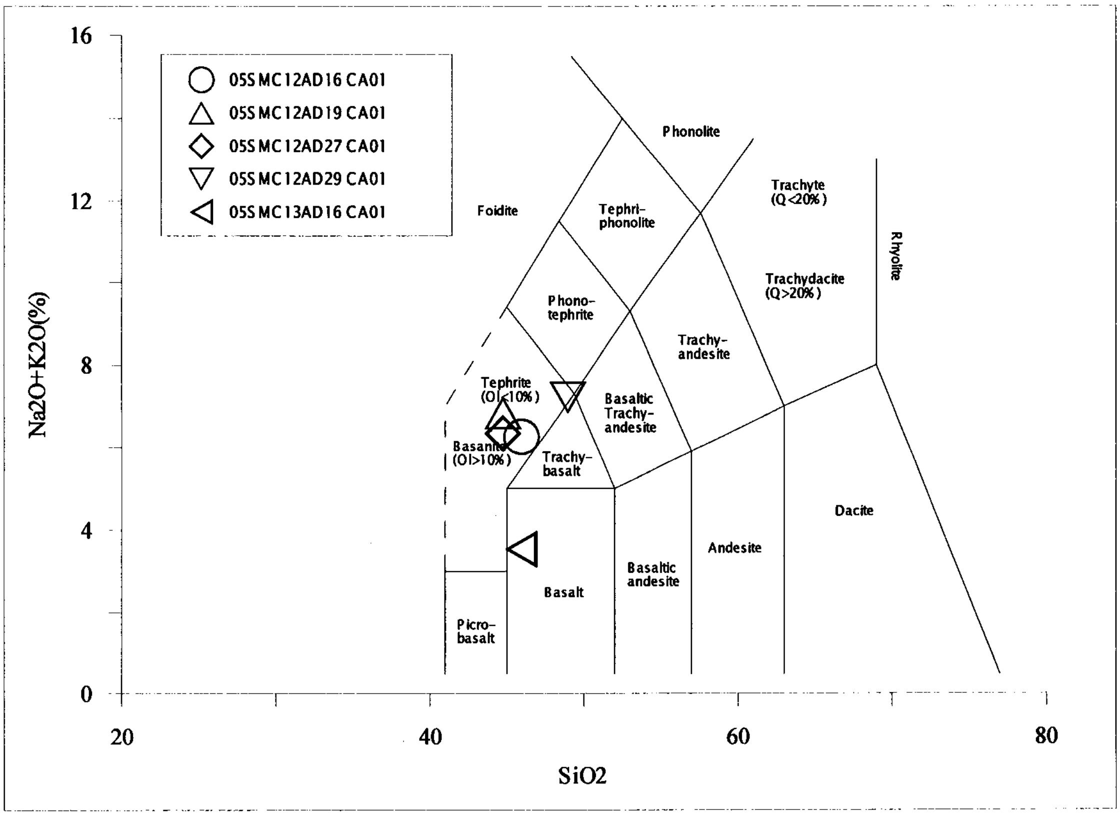


Figure 5-2-2 TAS Diagram (after Le Maitre et al., 1989)

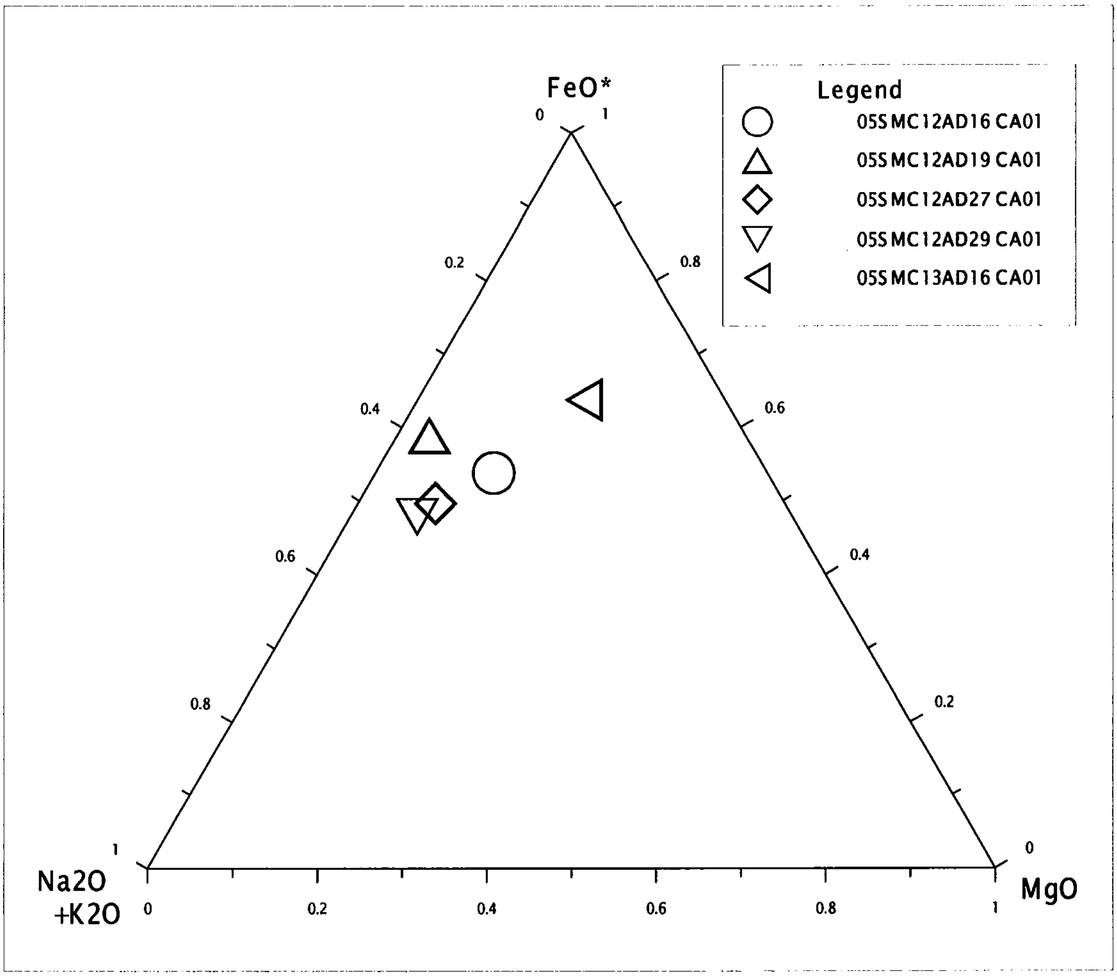


Figure 5-2-3 AFM Diagram

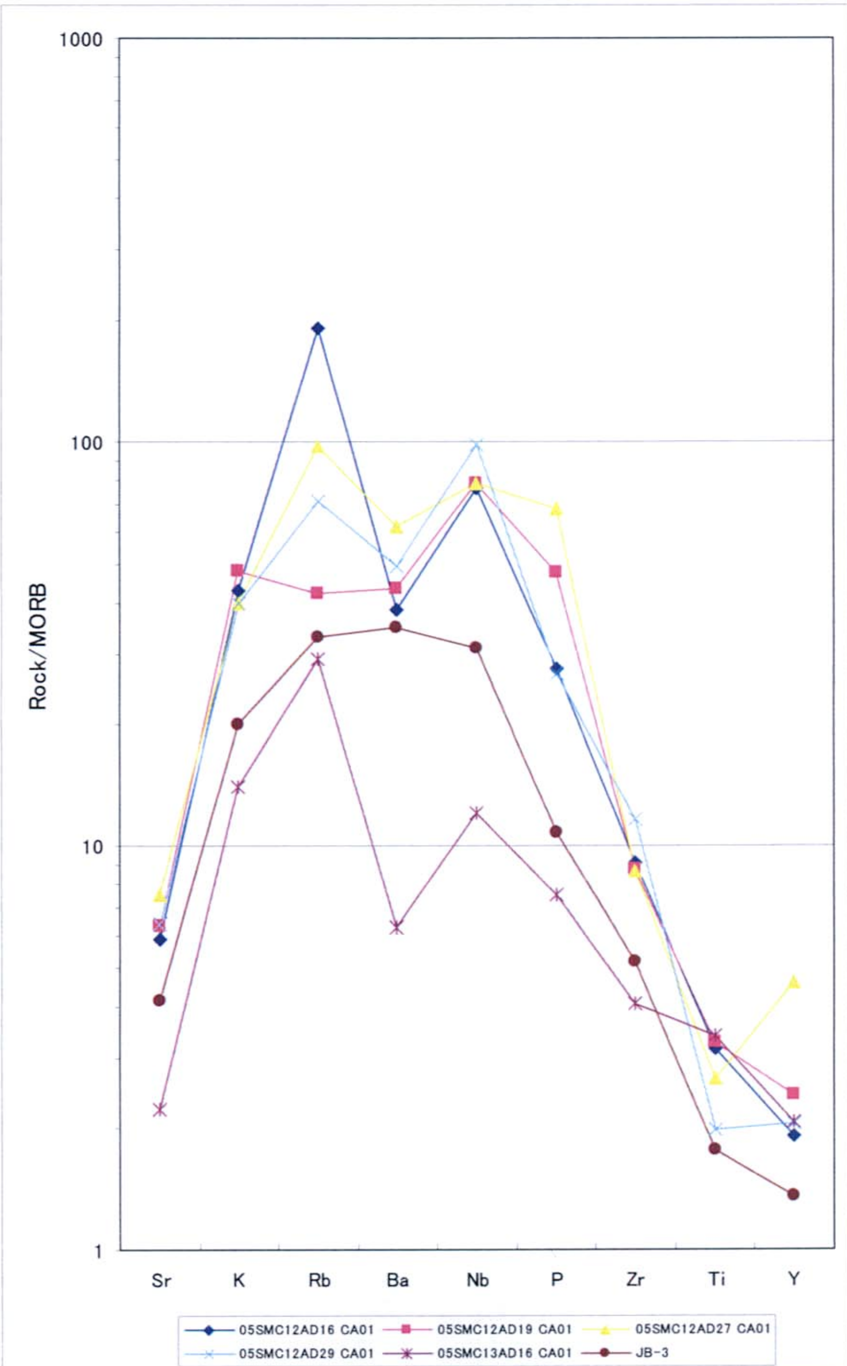


Figure 5-2-4　MORB Normalized Spiderdiagram

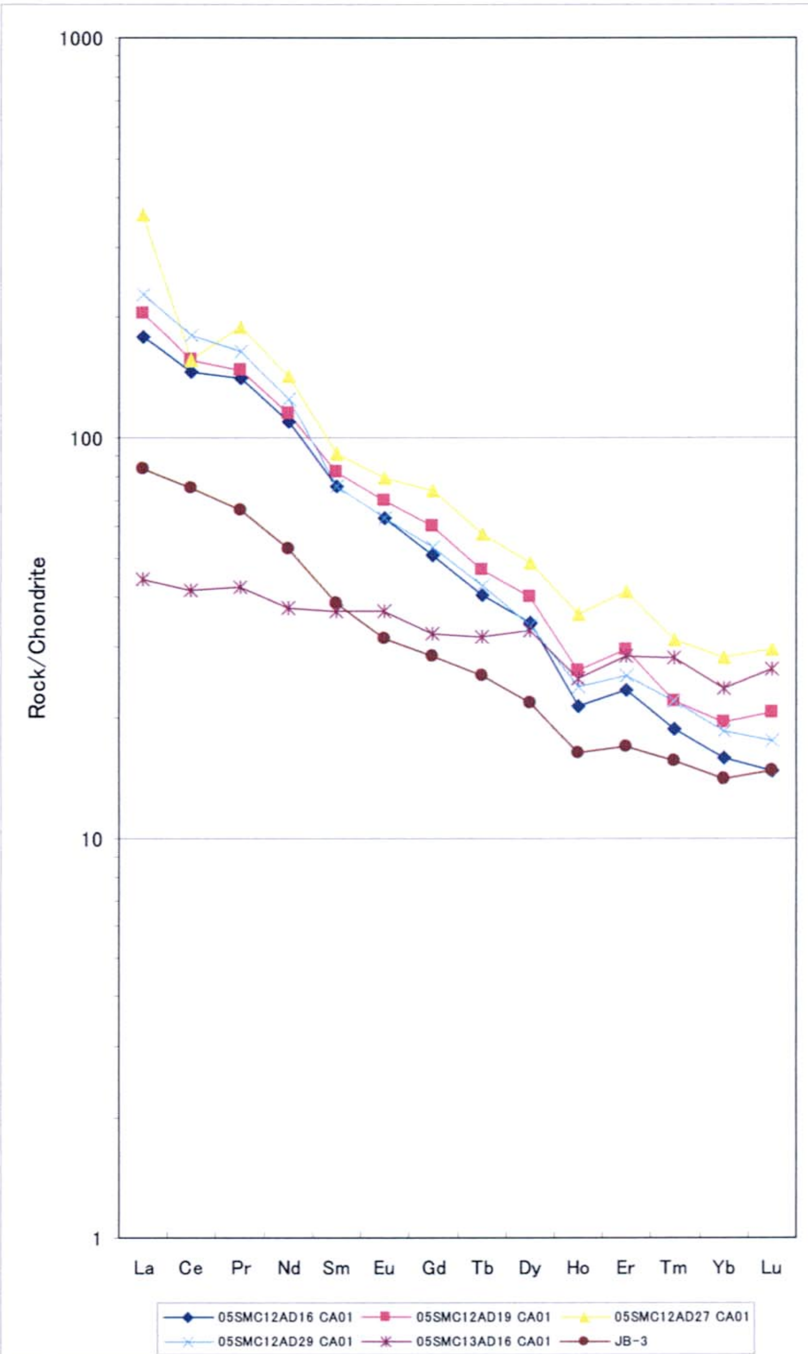


Figure 5-2-5 Chondrite Normalized REE Patterns

Table 5-2-4 Chemical Composition of MORB and Chondrite

	MORB after Sun et al., 1979 (ppm)		Chondrite after Wakita et al., 1971 (ppm)
Sr	114	La	0.34
K	580	Ce	0.91
Rb	1	Pr	0.121
Ba	8	Nd	0.64
Nb	1	Sm	0.195
P	300	Eu	0.073
Zr	50	Gd	0.26
Ti	5215	Tb	0.047
Y	25	Dy	0.3
		Ho	0.08
		Er	0.2
		Tm	0.032
		Yb	0.22
		Lu	0.034

On the spiderdiagram (Figure 5-2-4), there are clear differences of patterns between the samples of MC12 and MC13. Despite of similar values of Sr, Ti and Y, enrichments of K, Rb, Ba, Nb, P and Zr are clearly observed in MC12 samples compared to MC13 sample which show relatively depleted values of these elements. These enriched patterns of MC12 samples are similar to that of within plate alkali basalt such as ocean island basalt.

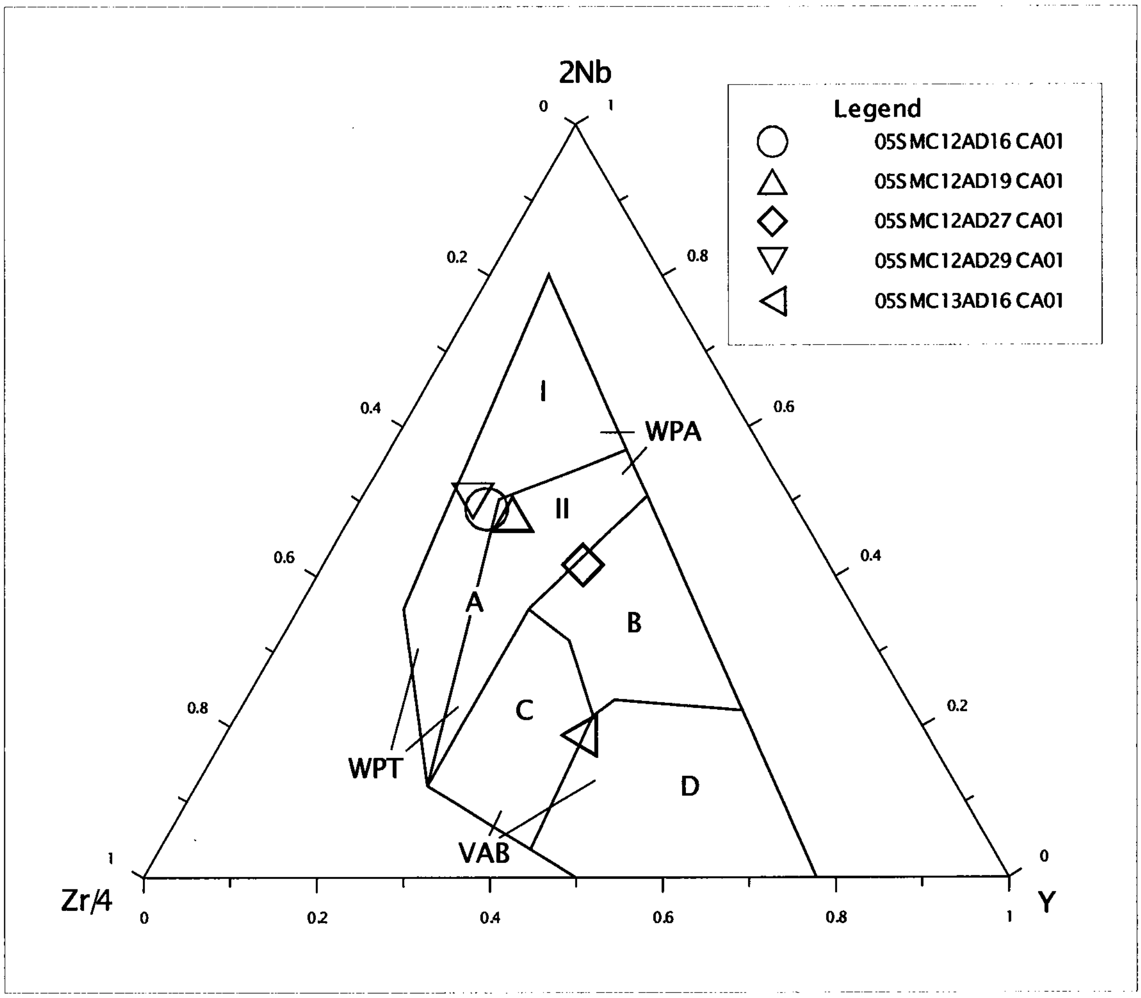
On the figure of chondrite normalized REE patterns (Figure 5-2-5), clear differences of pattern are, again, observed between samples MC12 and MC13. The samples of MC12 show patterns of steeply declined to right hand side with La as high as 200 to 400 time chondrite and 15 to 30 times chondrite Lu. The sample of MC13, on the other hand, shows a pattern of gently declined to right hand side with 45 times chondrite La and 30 times chondrite Lu. The former pattern of REE with enriched LRRE is observed for alkali rocks, typically, ocean island basalt (OAB). While, the pattern of MC13 with gentle sloop is similar to that of theleiitic rocks, most typically ocean island tholeiite. All of the samples does not show clear Eu anomaly.

For further considering tectonic environments of samples collected from MC12 and MC13 areas, discrimination diagrams using relatively immobile elements were constructed. They are Zr/4-2Nb-Y diagram of Meschende (1986) (Figure 5-2-6). 10MnO-TiO_2-10P_2O_5 diagram of Mulen (1983) (Figure 5-2-7) and Zr-Ti/100-3Y diagram of Pearce and Cann (1973) (Figure 5-2-8).

On Zr/4-2Nb-Y diagram, all of the samples of MC12 area are plotted in the field of within-plate alkali basalt with an exception of 05SMC12AD27CA01, which is plotted in E-type MORB. The sample of MC13, on the other hand, is plotted in field of N-Type MORB and Volcanic-Arc-Basalt.

Although 10MnO-TiO_2-10P_2O_5 diagram was constructed, all the samples of MC12 and MC13 have high P_2O_5 content possibly by enrichment through alteration episode. They, consequently, occupy the area very close to P_2O_5 corner in oceanic island basalt except MC13 sample, which has less P_2O_5 compared with other samples of MC12. Therefore, this diagram does not properly suggest tectonic environment for these rocks.

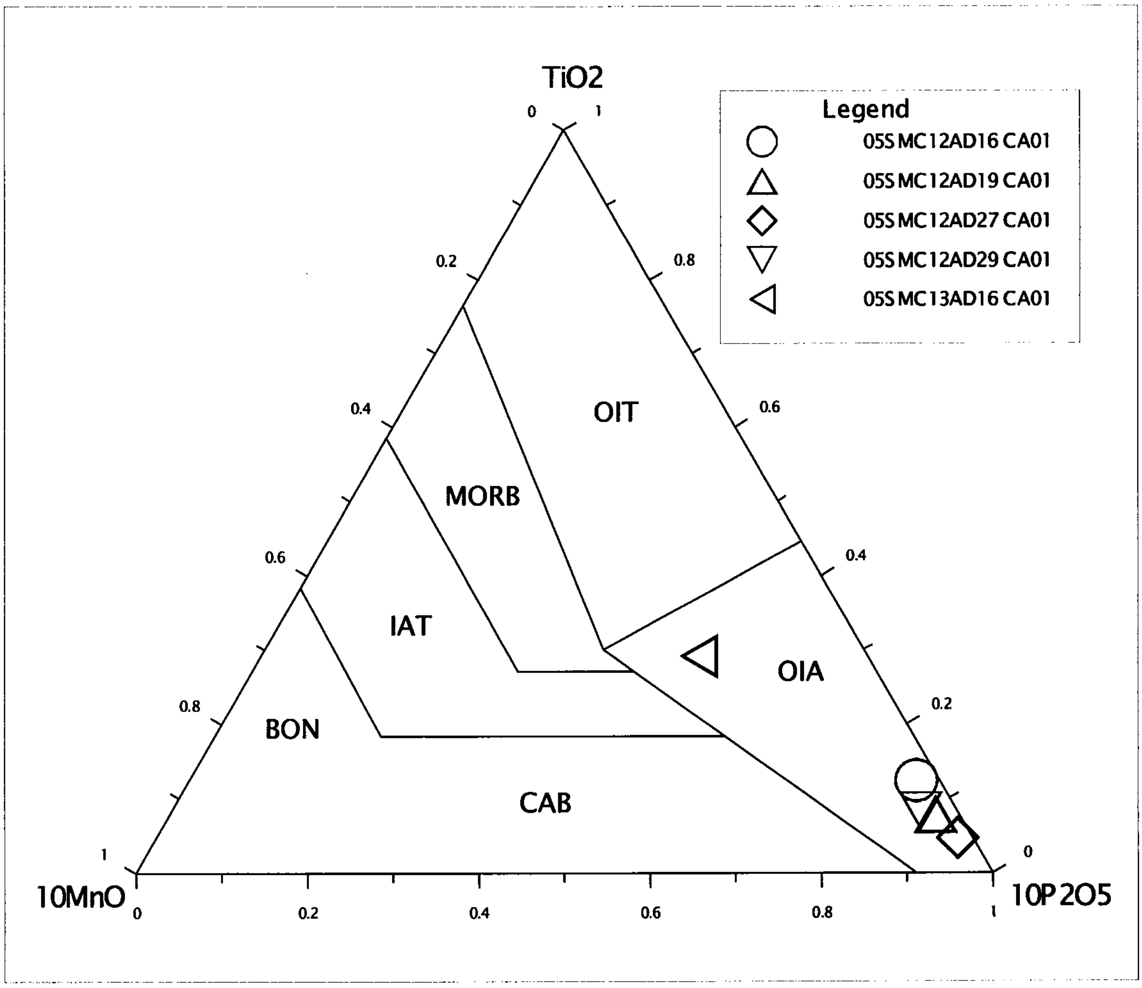
On Zr-Ti/100-3Y diagram, the samples of MC12 are distributed in the field of island-arc calc-alkaline basalt, while MC13 sample is plotted in the field of island-arc tholeiite.



AI, within-plate alkali basalts; AII, within-plate alkali basalts and within-plate tholeii
B, E-type MORB; C, within-plate tholeiites and volcanic-arc basalts;
D, N-type MORB and volcanic-arc basalts
WPA, within-plate alkali basalt; WPT, within-plate tholeiite, VAB, volcanic-arc basalt

Figure 5-2-6 Zr/4-2Nb-Y

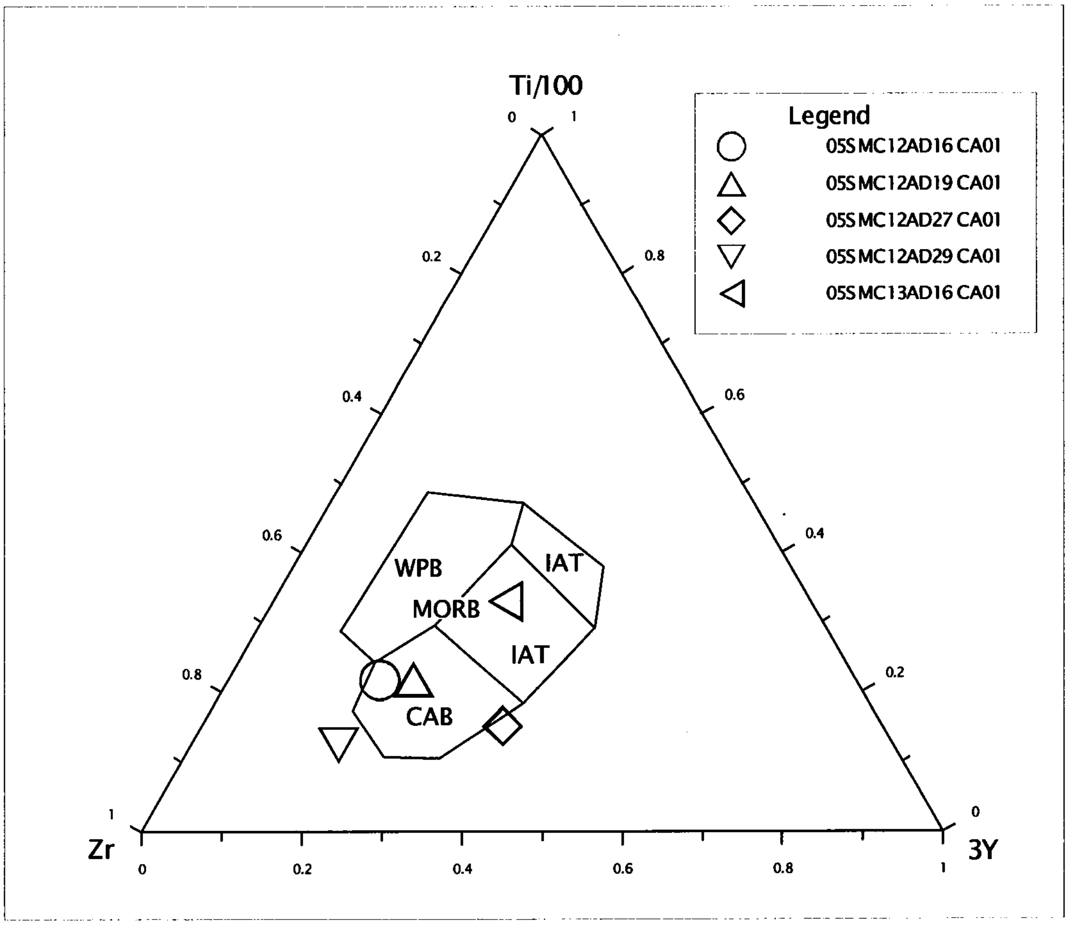
(fields of tectonic environment were taken from Meschende (1986))



OIT, ocean-island tholeiite or seamount tholeiite;
OIA, ocean-island alkali basalt or seamount alkali basalt;
CAB, island-arc calc-alkaline basalt;
IAT, island-arc tholeiite; BON, boninite

Figure 5-2-7 $10P_2O_5$-TiO_2-10MnO Diagram

(Field of tectonic environment were taken from Mullen (1983))



WPB, within-plate basalt;
CAB, island-arc calc-alkaline basalt;
IAT, island-arc tholeiite

Figure 5-2-8 3Y-Ti100-Zr Diagram

(fields of tectonic environment were taken from Pearce and Cann (1973))

(2) Summary

The analytical results of major elements of four samples from MC12 area and one sample of MC13 area show certain degree of alteration for these with high LOI, Fe_2O_3 and P_2O_5. Although SiO_2 seems to be decreased from original composition by alteration, MC12 samples clearly occupy the field of alkali rock on Alkali-Silica and TAS diagrams. The sample of MC13 with least alteration, on the other hand, shows sub-alkalic nature on the major elements chemistry.

On the spiderdiagram and chondorite normalized REE pattern, MC12 samples and MC13 sample show a quite different nature. The former shows chemical nature of alkalic rock, such as oceanic island basalt, with enrichment in LIL on the spiderdiagram and steep right hand side dipping chondrite normalized REE patterns. While the latter without clear enrichment in LIL in spiderdiagram and gently dipping REE pattern of 40 to 30 times chondrite La shows tholeiitic nature, such as arc-basalt and oceanic island tholeiite.

For further considering tectonic environment of igneous rock, discrimination diagrams using immobile elements and incompatible elements are constructed. On Zr/4-2Nb-Y diagram, all of the samples of MC12 are plotted in the field of within-plate alkali basalt with an exception of 05SMC12AD27CA01, which is distributed outside of but close to the field of within-plate alkali basalt. The sample of MC13, on the other hand, is plotted in field of N-Type MORB and Volcanic-Arc-Basalt. All of the samples are distributed in the field of ocean-island alkali basalt on $10MnO$-TiO_2-$10P_2O_5$ diagram, however, considering the possible introduction of P_2O_5 through alteration episode, this diagram can not be applicable for these samples to discriminate tectonic environment. On Zr-Ti/100-3Y diagram, the samples of MC12 are distributed in the field of island-arc calc-alkaline basalt, while MC13 sample is plotted in the field of island-arc tholeiite.

Considering all the chemical natures of the samples, the most probable interpretation of MC12 samples is that they are alkali basalt of oceanic-island setting.

The sample of MC13 shows tholeiitic nature. It is not clear whether it is ocean-island tholeiite or island arc tholeiite, however, no clear depletion of Nb, which is commonly depleted in the rocks of island arc setting, suggest ocean-island setting for this rock, possibly oceanic island tholeiite.

5-3. Identification of Minerals by X-ray Diffraction Analysis

5-3-1 Samples

As shown on Table 5-3-1, three samples were selected for X-ray deflection analysis. The X-ray deflection analysis was conducted at Dowa Techno Research and identification of minerals from X-ray chart was done by Y. Negishi and K. Maeda of Mitsubishi Materials Natural Resources Corp.

Table 5-3-1 Samples for X-ray Diffraction Analysis

Ser. No.	Sea Mount.	Sample No.	Depth of Bottom Touch (m)	Piece No. of Sample	Lithology
1	MC12	05SMC12AD27_XRD01	2,209	c2	Tuffaceous Siltstone
2	MC12	05SMC12AD28_XRD01	1,858	c2	Altered Basalt
3	MC13	05SMC13AD15_XRD01	1,724	–	Fillings of Interstice

5-3-2 Sample Preparation and Analytical Method

The samples were crushed and dried at room temperature, then pulverized using vibration mill and agate mortar. The X-ray diffraction analysis was conducted using non-oriented samples. The abundance of each mineral was estimated by quartz index using pure quartz sample prepared by the same way as rock samples.

The analyses were conducted using Geiger Flex, Rigaku by the settings given below.

X-ray: Cu K-ALPHA 1/30 kV/15mA
Attachment: Standard Sample Holder
Radiation/Scatter Slit: 1 deg.
Target Slit: 0.30mm
Scanning Mode: continuous
Scanning Speed: 2,000 deg./min
Scanning Step: 0.050 deg.
Scanning Angle: 2.000 to 70.000 deg.

5-3-3. Results of Analysis and Considerations

The results of X-ray diffraction analyses are given in Table 5-3-2.

The relative abundance of minerals is estimated by quartz index using following equation.

$$Q.I. = Im/Iq \times 100$$

Q.I.= quartz index

Im: the maximum peak of each mineral

Iq: the maximum peak of pure quartz obtained by this anlysis

11,043 cps was obtained by this analysis

Table 5-3-2 Results of X-ray diffraction Analyses

Ser. No.	Sample No.	Silicates				Others
			Feldspar		Clay	
		Quartz	K-feldspar	Albite	Smectite	Apatite
1	05SMC12AD27 XRD01		1.6		0.9	2.9
2	05SMC12AD28 XRD01			15.0		
3	05SMC13AD15 XRD01	19.7				

The results of X-ray diffraction analyses were given below on each sample basis.

05SMC12AD27 XED01

Potash feldspar, smectite and apatite were identified from this sample. Although this sample was described as tudffaceous siltstone, the board peak characterizing amorphous materials was not identified. This is siltstone consisting of mainly potash feldspar with secondary minerals of smectite and apatite.

05SMC12AD28 XRD01

Although this sample was described as altered basalt, no secondary mineral such as clay minerals was identified and albite is the only mineral identified by x-ray diffraction. Despite of the appearance, the degree of the alteration of this rock seems to be weak, possibly affected only by oxidation.

05SMC13AD15 XRD01

This sample was described as agate filling interstices. Only quartz was identified from this sample and the broad peak reflecting the occurrence of amorphous materials was not identified.

5-4 Microscopic Observation of Manganese Crust

5-4-1 Samples

A total of 12 polish sections of manganese crust were prepared for microscopic observation (Table5-4-1). The photographs of hand specimen are shown on Plate III. The descriptions of hand specimen and microscopic work were conducted by Dr. K. Maeda, Mitsubishi Materials Natural Resources Corporation.

5-4-1 Manganese Crust Samples for Microscopic Observation

Ser. NO.	Sample No.	Water Depth (m)	Piece No. of Samples	Lithology	Remarks
1	05SMC12AD15 _PS01	2,437	a3	Manganese crust	continuous sample
2	05SMC12AD15 _PS02			Manganese crust	continuous sample
3	05SMC12AD15 _PS03			Manganese crust	continuous sample
4	05SMC12AD15 _PS04			Manganese crust	continuous sample
5	05SMC12AD16 _PS01	2,004	a3	Manganese crust	continuous sample
6	05SMC12AD16 _PS02			Manganese crust	continuous sample
7	05SMC12AD16 _PS03			Manganese crust	continuous sample
8	05SMC12AD16 _PS04			Manganese crust	continuous sample
9	05SMC12AD16 _PS05		—	Strongly Altered Rock	massive goethite
10	05SMC12AD29 _PS01	2,385	a2	Manganese crust	bulk sample
11	05SMC12AD29 _PS06		a4	Manganese crust	continuous sample
12	05SMC12AD29 _PS07			Manganese crust	continuous sample

5-4-2 Descriptions of Hand Specimen

Each hand specimen was described prior to investigations by microscope. The results of descriptions were given below.

<u>05SMC12AD15 PS01 – PS04</u>

13cm long cross section of manganese crust. Although it is not clear but botryoidal texture of 5mm across is observed on the surface. From the surface to 8cm: Black and massive manganese oxides. Network of irregular and unclear fracture occurs entirely and limonite filling the pores of 0.5mm across is occasionally observed along the fracture. From 8cm to the end: Pale brownish gray calcareous fillings (rock fragments?) of 3 to 5mm across increases reaching to 40vol% and they occur radiating outward from inner part to surface. It has smooth surface and it does not attach to hand.

<u>05SMC12AD16 PS01 – PS04</u>

13cm long cross section of black to pale brownish gray manganese crust. The surface shows botryoidal texture of 2cm across. From the surface to below, the amount of irregular shaped patch to network of pale brownish gray calcareous fillings (rock fragments ?) increases to 30 vol. %. Pores of 1mm across are rare and unclear, 2 to 3mm wide network of limonite is scattered entirely. It has smooth surface and it does not attach to hand.

05SMC12AD16 PS05

Black massive limonite / goethite. Massive and it does not show any particular texture. Pores of 1 to 2mm across are scattered and milky white calcite is rarely found filling pores of less than 1mm across. It has smooth surface and it does not attach to hand.

05SMC12AD29 PS01

3 X 3cm platy fragments of manganese crust. It is black and massive with botryoidal surface of 2 to 3mm across. In lower part, a layer with scattered distribution of pale brownish gray calcareous fillings of 1 to 2mm across occurs showing relatively sharp contact with upper part without calcareous fillings. In the upper part, abundant pores of less than 5mm across filled by limonite occur in the network band of 2 to 3 mm wide. It has relatively smooth surface and it does not attach to hand.

05SMC12AD29 PS06-PS07

7cm long cross section of manganese oxides. It is black to pale brownish gray, and pores of 2 to 3mm across are irregularly distributed. Limonite is attached in some of the pores. In upper layer from the surface to 5cm, pores of less than 5mm across are filled by calcareous fillings (fragments of carbonate rock?). The surface is slightly granular, it attaches to hand.

5-4-3 Results of Microscopic Observation

The results of microscopic observation of polished section are given in Plate IV with micrographs, and a summary of descriptions is given in Table 5-4-2.

5-4-2 Microscopic Observation of Manganese Crust

Ser. No.	Area	Sample No.	Water Depth (m)	Piece No. of Samples	Lith°ligy	Texture	Ratio of Ore Minerals (%)	Ore Mineral				Gangue Mineral			Clastics				
								Vd	Py	Geo	Mg	Q	Cc	Ap	Q	Pl	Cc	Ap	Rock Fragments
1	MC12	05SMC12AD15 PS01	2437	a3	Manganese crust	massive to spotted	90	◎							·	·			
2		05SMC12AD15 PS02			Manganese crust	massive to colloform	88	◎							·	△			calcareous rock(·)
3		05SMC12AD15 PS03			Manganese crust	massive to colloform	79	◎							·	·			calcareous rock(○)
4		05SMC12AD15 PS04			Manganese crust	colloform	79	◎							·	·			calcareous rock(○)
5		05SMC12AD16 PS01	2004	a3	Manganese crust	massive to spotted	77	◎								·			
6		05SMC12AD16 PS02			Manganese crust	spotted to colloform	84	◎	·						·	△			Calcareous rock(○)
7		05SMC12AD16 PS03			Manganese crust	spotted to network	82	◎							·	○			calcareous rock(○) volcanic rock(·)
8		05SMC12AD16 PS04			Manganese crust	massive to network	90	◎							·	△			calcareous rock(○)
9		05SMC12AD16 PS05		—	Strongly Altered Rock	massive to oolitic	85			◎		△							
10		05SMC12AD29 PS01	2385	a2	Manganese crust	spotted to colloform	89	◎							·	○			calcareous rock(◎) volcanic rock(○)
11		05SMC12AD29 PS06		a4	Manganese crust	massive to colloform	60	◎							·	△			volcanic rock(·)
12		05SMC12AD29 PS07			Manganese crust	colloform	94	◎							·	△			calcareous rock(○)

Vd: vernadite
Py: pyrite
Geo: goethite
Mg: magnetite

Q: quartz
Cc: calcite
Ap: apatite

Pl: plagioclase

◎ ;abundant(>30)
○ ;common(10~30)
△ ;rare(3~10)
· ;trace(<3)

5-5 X-ray Diffraction Analyses of Manganese Crust

5-5-1 Samples

The X-ray diffraction analyses of manganese crust were conducted for 5 samples as shown in Table 5-5-1.

The X-ray deflection analysis was carried out at Dowa Techno Research and identification of minerals from X-ray chart was done by Y. Negishi and K. Maeda of Mitsubishi Materials Natural Resources Corp.

5-5-1 Samples for X-ray diffraction Analyses

Ser. No.	Area	Sample No.	Water Depth of Bottom Touch (m)	Piece No. of Samples	Lithology
1	MC12	05SMC12AD15_XRD01	2,437	a3	manganese crust
2	MC12	05SMC12AD16_XRD01	2,004	a3	manganese crust
3	MC12	05SMC12AD16_XRD02		—	strongly altered rock
4	MC12	05SMC12AD29_XRD01	2,385	a2	manganese crust
5	MC12	05SMC12AD29_XRD03		a4	manganese crust

5-5-2 Sample Preparation and Analytical Method

The samples were crushed and dried at room temperature, then pulverized using vibration mill and agate mortar. The X-ray diffraction analysis was conducted using non-oriented samples. The abundance of each mineral was estimated by quartz index using pure quartz sample prepared by the same way as manganese crust samples.

The analyses were conducted using Geiger Flex, Rigaku by the settings given below.

X-ray: Cu K-ALPHA 1/30 kV/15mA
Attachment: Standard Sample Holder
Radiation/Scatter Slit: 1 deg.
Target Slit: 0.30mm
Scanning Mode: continuous
Scanning Speed: 2,000 deg./min
Scanning Step: 0.050 deg.
Scanning Angle: 2.000 to 70.000 deg.

5-5-3. Results of Analysis and Considerations

The results of X-ray diffraction analyses are given in Table 5-5-2.

The relative abundance of minerals is estimated by quartz index using following equation.

$$Q.I. = Im/Iq \times 100$$

Q.I. : quartz index

Im : the maximum peak of each mineral

Iq: : the maximum peak of pure quartz obtained by this analysis

11,043 cps was obtained by this analysis

Table 5-5-2 Results of X-ray Diffraction Analysis

Ser. No.	Sample No.	Silicate			Carbonates	Mn Oxides	Others
		Silica	Feldspar	Clay Minerals	Calcite	Vernadite	Goethite
		Quartz	Plagioclase	Sericite/ Smectite			
1	05SMC12AD15_XRD01	0.4	0.5			0.4	
2	05SMC12AD16_XRD01	0.3	0.4		0.8	0.4	
3	05SMC12AD16_XRD02			0.2			2.1
4	05SMC12AD29_XRD01	0.6	0.6			0.4	
5	05SMC12AD29_XRD03				0.6	0.4	

The results of X-ray diffraction analyses are given below on each sample basis.

05SMC12AD15 XRD01

The X-ray diffraction analysis shows that the manganese oxide forming this manganese crust is vernadite (beta-MnO_2). Clastics, such as quartz and plagioclase, were identified. Q.I. shows similar value for all three minerals.

05SMC12AD16 XRD01

The manganese oxide of this sample is vernadite (beta-MnO_2). In addition to this, quartz, plagioclase and calcite of either detrital or secondary origin were identified. Calcite shows the highest Q.I. of 0.8 and vernadite, quartz and plagioclase have similar values of 0.3 to 0.4.

05SMC12AD16 XRD02

Mixed layers of sericite/chlorite and goethite were identified. The goethite shows high Q.I .of 2.1 compared to 0.2 for the mixed layers of sericite/smectite. This corresponds with hand specimen description of this sample as goethite pebble.

05SMC12AD29 XRD01

Vernadite (beta-MnO_2), quartz and plagioclase were identified. Quartz and plagioclase show higher Q.I. of 0.6 compared to 0.4 for vernadite.

05SMC12AD29 XRD03

Vernadite (beta-MnO_2) and calcite of secondary origin were identified and both of them show Q.I. of, respectively, 0.4 and 0.6.

5-6 Chemical Analyses of Manganese Crust

5-6-1 Samples

A total of 35 samples including two standard samples were chosen for chemical analyses of 36 elements (Table 5-6-1).

Table 5-6-1 Manganese Crust Samples for Chemical Analyses

Ser. No.	Area	Sample No.	Water Depth of Bottom touch (m)	Piece No. Of Samples	Remarks
1	MC12	05SMC12AD15 CM01	2,437	a1	bulk
2		05SMC12AD15 CM02		a2	bulk
3		05SMC12AD15 CM03		a3	bulk
4		05SMC12AD15 CM04			layer I
5		05SMC12AD15 CM05			layer II
6		05SMC12AD15 CM06			layer III
7		05SMC12AD15 CM07			layer IV
8		05SMC12AD16 CM01	2,004	a1	bulk
9		05SMC12AD16 CM02		a2	bulk
10		05SMC12AD16 CM03		a3	bulk
11		05SMC12AD16 CM04			layer I
12		05SMC12AD16 CM05			layer II
13		05SMC12AD16 CM06			layer III
14		05SMC12AD16 CM07		—	massive goethite
15		05SMC12AD17 CM01	1,772	a1	bulk
16		05SMC12AD19 CM01	1,873	a2	bulk
17		05SMC12AD19 CM02		a3	bulk
18		05SMC12AD20 CM01	1,562	a1	bulk
19		05SMC12AD22 CM01	1,822	a1	bulk (crust fragment)
20		05SMC12AD28 CM01	1,858	a1	bulk
21		05SMC12AD29 CM01	2,385	a1	bulk
22		05SMC12AD29 CM02		a2	bulk
23		05SMC12AD29 CM03		a3	bulk
24		05SMC12AD29 CM04			layer I
25		05SMC12AD29 CM05			layer II
26		05SMC12AD29 CM06			layer III
27		05SMC12AD29 CM07		a4	bulk
28		05SMC12AD29 CM08			layer I
29		05SMC12AD29 CM09			layer II
30		05SMC12AD30 CM01	2,370	a1	Bulk
31		05SMC12AD30 CM02		a2	upper layer of slab
32		05SMC12AD30 CM03			lower layer of slab (for reference)
33	MC13	05SMC13AD15CM01	1,724	a1	—
34	Standard JMn-1		—	—	—
35	Standard JMn-1		—	—	—

5-6-2 Elements of Chemical Analyses

The chemical analyses of 36 elements given below were conducted for all samples.

- Co、Ni、Cu、Mn、Fe、Pb、Zn、Ti、Mo、V、Si、Al、Ca、Na、K、P、Ba、Sr、LOI、H_2O^+、H_2O^- (detection limit: 0.01%)
- Pt (detection limit: 0.01ppm)
- REE (La、Ce、Pr、Nd、Sm、Eu、Gd、Tb、Dy、Ho、Er、Tm、Yb、Lu) (detection limit: 0.01ppm)

5-6-3 Analytical Methods

All the chemical analyses including samples preparation were conducted at ALS Chemex, Canada. Major elements、such as Mn, Ti, Si, Al, Ca, Na, K, P, Fe, were analyzed by Inductively Coupled Plasma Spectrometry (Vista Pro ICP-AES, Varian). While, trace elements analyses, Co, Ni, Cu, Pb, Zn, Mo, V, Ba, Sr, REE (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu), were conducted by Inductively Coupled Plasma-Mass Spectrometry (Elan9000 ICP-MS, Perkin Elmer). Assaying of Pt was conducted by fire assay with NiS collection and quantified by Inductively Coupled Plasma Spectrometry (Vista Pro ICP-AES, Varian). LECO (RMC-100、LECO) was used for determination of $H2O^+$、$H2O^-$ and LOI (ignition loss) was gravitationally determined.

The sample weight was determined following the method of Terashima et al. (1995). Prior to the chemical analyses, after drying, crushing and pulverizing samples were dried for 10 hours by dry oven and the weight was measured quickly after taking out the sample from the dry oven.

5-6-4 Analytical Results

The analytical results are given on Table 5-6-2, and Table 5-6-3 shows analytical results of ALS Chemex standard samples simultaneously analyzed with MC12 and MC13 samples.

Table 5-6-2 Results of Chemical Analyses of Manganese Crust

Sample No.	%																					ppm															
	Co	Ni	Cu	Mn	Fe	Pb	Zn	Ti	Mo	V	Si	Al	Ca	Na	K	P	Ba	Sr	LOI	H2O+	H2O-	Pt	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Mn/Fe
05SMC12AD15 CM01	0.12	0.13	0.11	7.04	21.80	0.04	0.06	1.45	0.01	0.05	9.82	6.36	1.84	4.06	2.22	0.44	0.16	0.10	13.35	6.81	3.09	0.18	152	281	27.9	112	22.9	6.6	28.4	4.4	26.2	5.8	16.4	2.4	15.0	2.4	0.32
05SMC12AD15 CM02	0.25	0.20	0.14	10.80	22.90	0.07	0.06	1.45	0.02	0.04	6.62	3.88	1.35	3.28	1.22	0.52	0.18	0.13	14.95	7.34	3.42	0.35	271	530	46.6	186	37.3	10.6	45.6	6.9	41.8	9.1	26.2	3.8	24.5	3.9	0.47
05SMC12AD15 CM03	0.22	0.20	0.10	11.62	23.30	0.08	0.07	1.45	0.04	0.04	5.71	2.80	1.50	2.88	0.96	0.59	0.21	0.15	14.85	6.79	1.65	0.12	303	551	57.6	233	45.9	12.8	55.4	8.7	48.8	10.6	29.6	4.3	26.0	4.0	0.50
05SMC12AD15 CM04	0.33	0.30	0.09	16.88	20.30	0.11	0.05	0.63	0.06	0.05	4.01	1.32	1.98	2.96	0.82	0.74	0.13	0.16	17.85	7.43	3.15	nss	320	614	63.1	256	52.3	14.6	63.0	9.6	54.8	12.0	33.1	4.8	29.7	4.8	0.83
05SMC12AD15 CM05	0.40	0.32	0.07	17.50	20.10	0.14	0.06	0.93	0.06	0.05	2.76	0.88	1.83	2.92	0.76	0.59	0.19	0.18	17.40	8.81	1.93	0.10	381	845	73.2	291	56.8	15.7	68.1	10.4	59.9	13.0	36.0	5.2	31.5	4.9	0.87
05SMC12AD15 CM06	0.19	0.15	0.09	11.19	25.40	0.09	0.07	2.05	0.03	0.04	5.12	1.94	1.36	2.52	0.76	0.50	0.27	0.16	14.55	7.64	2.30	0.19	340	659	69.2	271	55.2	15.0	62.4	9.8	56.1	11.8	32.8	4.6	27.6	4.3	0.44
05SMC12AD15 CM07	0.07	0.14	0.14	7.62	24.90	0.03	0.07	1.17	0.02	0.05	8.49	4.60	1.36	3.00	1.14	0.70	0.17	0.11	13.00	7.69	3.55	0.20	209	221	37.4	151	30.7	8.9	36.9	5.8	35.3	7.5	21.9	3.0	19.4	3.0	0.31
05SMC12AD16 CM01	0.24	0.19	0.06	11.81	25.00	0.10	0.07	1.68	0.03	0.05	5.03	2.12	2.22	2.64	0.82	0.78	0.23	0.16	15.05	6.79	4.26	0.12	290	661	52.0	208	41.9	11.8	50.9	7.9	47.3	10.3	28.9	4.2	25.6	4.0	0.47
05SMC12AD16 CM02	0.21	0.19	0.08	10.84	23.00	0.08	0.06	0.21	0.03	0.04	5.54	3.08	4.14	2.90	1.02	0.85	0.17	0.14	14.65	6.48	3.53	0.11	244	465	41.6	172	33.5	10.0	43.3	6.7	40.7	9.0	26.3	3.8	23.7	3.8	0.47
05SMC12AD16 CM03	0.26	0.19	0.07	11.31	23.50	0.09	0.06	1.67	0.03	0.05	6.06	3.16	2.56	3.04	1.02	0.66	0.21	0.15	15.40	7.19	3.99	0.14	263	599	48.0	195	38.9	10.8	46.9	7.4	41.7	9.6	25.6	3.9	23.0	3.7	0.48
05SMC12AD16 CM04	0.44	0.31	0.06	16.03	21.40	0.13	0.05	1.05	0.05	0.04	4.09	1.54	2.03	2.96	0.88	0.71	0.18	0.17	17.20	8.10	3.84	0.14	291	870	50.9	208	41.7	11.8	51.0	7.8	46.4	10.4	29.2	4.3	26.6	4.4	0.75
05SMC12AD16 CM05	0.20	0.14	0.07	9.84	23.90	0.09	0.07	2.42	0.02	0.05	6.64	3.08	2.00	2.68	1.08	0.50	0.22	0.15	14.10	7.24	2.98	0.13	266	582	50.9	204	41.1	11.4	49.5	7.6	44.4	9.3	26.4	3.7	23.4	3.5	0.41
05SMC12AD16 CM06	0.08	0.10	0.08	6.47	21.30	0.03	0.07	0.79	0.02	0.05	8.65	5.78	5.49	3.64	1.44	0.80	0.16	0.12	15.25	6.40	2.70	0.14	190	220	31.4	129	27.3	8.1	34.2	5.4	34.4	7.8	23.2	3.3	20.9	3.4	0.30
05SMC12AD16 CM07	0.00	0.01	0.07	0.11	50.00	0.00	0.04	0.02	0.00	0.01	2.77	0.66	0.16	0.20	0.30	0.46	0.00	0.01	11.80	11.10	1.16	0.01	6	9	1.1	4	0.9	0.3	1.1	0.2	1.1	0.3	0.8	0.1	0.9	0.2	0.00
05SMC12AD17 CM01	0.69	0.31	0.08	15.88	22.50	0.13	0.04	1.36	0.03	0.05	3.16	1.80	3.00	3.52	1.00	0.59	0.18	0.15	18.65	6.86	4.31	1.02	289	1135	44.8	181	35.9	10.1	44.0	6.7	40.5	9.2	26.9	3.9	25.0	4.1	0.71
05SMC12AD19 CM01	0.31	0.24	0.08	12.86	26.90	0.11	0.06	1.35	0.03	0.04	4.91	1.90	1.60	2.66	0.84	0.58	0.21	0.15	15.15	7.97	2.54	0.19	276	709	48.5	200	39.7	11.2	48.8	7.6	45.1	9.9	28.1	4.0	25.2	4.0	0.48
05SMC12AD19 CM02	0.29	0.24	0.08	12.97	24.00	0.13	0.07	1.36	0.03	0.04	5.71	2.22	1.56	2.78	0.88	0.55	0.23	0.16	14.65	6.55	4.27	0.16	257	846	44.5	179	36.9	10.4	43.1	6.6	40.4	8.4	25.1	3.5	22.8	3.5	0.54
05SMC12AD20 CM01	nss	nss	nss	19.52	nss	0.15	0.05	nss	0.06	0.06	2.17	nss	nss	nss	nss	nss	0.11	0.17	18.20	6.29	8.57	0.19	322	741	59.4	244	48.0	13.2	58.0	9.0	51.8	11.8	33.4	4.9	30.3	4.9	-
05SMC12AD22 CM01	0.76	0.32	0.11	17.35	21.70	0.14	0.05	1.35	0.04	0.04	2.71	1.32	2.08	3.62	0.94	0.57	0.20	0.17	17.90	8.73	3.85	1.28	320	1295	52.0	207	41.3	11.2	48.7	7.3	43.7	9.9	29.2	4.2	27.0	4.3	0.80
05SMC12AD28 CM01	0.22	0.18	0.11	10.57	24.10	0.12	0.07	2.05	0.02	0.05	7.15	3.12	1.53	2.84	1.02	0.47	0.22	0.14	13.00	6.75	2.99	nss	192	712	35.4	140	29.3	8.4	34.7	5.3	31.6	6.6	18.9	2.7	17.2	2.7	0.44
05SMC12AD29 CM01	0.34	0.29	0.10	14.37	21.70	0.13	0.06	1.32	0.04	0.05	4.72	1.86	1.87	2.88	0.90	0.57	0.19	0.16	15.50	6.58	4.67	0.12	304	721	58.7	234	45.0	12.6	54.4	8.4	49.7	10.4	29.9	4.2	26.8	4.2	0.66
05SMC12AD29 CM02	0.34	0.30	0.11	16.03	21.60	0.13	0.06	1.20	0.05	0.04	4.49	1.66	1.87	2.90	0.86	0.61	0.20	0.17	16.35	6.87	6.12	0.13	306	752	59.0	233	46.7	13.0	54.2	8.4	49.2	10.0	29.5	4.1	26.1	4.0	0.74
05SMC12AD29 CM03	0.28	0.25	0.12	12.74	23.60	0.09	0.06	1.33	0.04	0.04	5.14	2.70	1.66	3.24	0.96	0.62	0.20	0.15	15.45	4.88	4.56	0.32	327	611	58.3	236	47.4	13.4	58.6	9.1	51.5	11.5	32.2	4.7	28.8	4.7	0.54
05SMC12AD29 CM04	0.33	0.31	0.09	16.34	21.10	0.12	0.05	0.75	0.05	0.05	4.00	1.42	1.98	2.84	0.82	0.73	0.15	0.17	16.60	4.07	1.51	nss	324	652	62.2	255	52.4	14.5	61.5	9.6	55.1	12.0	33.8	4.9	30.2	4.8	0.77
05SMC12AD29 CM05	0.46	0.35	0.10	17.12	20.70	0.13	0.06	1.04	0.06	0.04	3.26	1.24	1.94	3.12	0.86	0.66	0.17	0.17	17.15	6.77	5.23	0.15	332	784	58.7	235	47.8	13.4	56.5	8.8	52.5	11.4	33.3	4.7	30.5	4.8	0.83
05SMC12AD29 CM06	0.14	0.16	0.12	9.37	26.30	0.06	0.07	1.56	0.02	0.03	6.13	3.30	1.34	3.08	1.00	0.56	0.21	0.14	14.20	7.60	3.73	0.28	315	431	57.1	229	44.8	13.0	56.3	8.6	51.5	11.2	32.4	4.5	28.1	4.4	0.36
05SMC12AD29 CM07	0.39	0.25	0.15	12.90	23.10	0.10	0.05	1.52	0.03	0.04	4.82	2.98	2.14	3.26	1.18	0.50	0.19	0.15	16.55	6.99	5.09	0.56	303	789	51.4	204	41.6	11.6	49.1	7.5	45.2	9.7	28.3	4.1	25.9	4.3	0.56
05SMC12AD29 CM08	0.51	0.30	0.13	16.34	20.80	0.12	0.05	1.38	0.03	0.04	3.57	1.88	2.45	3.20	0.98	0.54	0.18	0.16	18.00	7.30	3.28	0.61	345	991	60.1	241	47.2	13.2	56.7	8.5	51.3	11.0	32.4	4.6	29.6	4.8	0.79
05SMC12AD29 CM09	0.21	0.16	0.16	10.03	25.10	0.07	0.06	1.52	0.02	0.04	6.29	3.62	1.72	3.12	1.16	0.47	0.20	0.13	14.70	7.26	2.28	0.55	292	519	50.8	204	39.7	11.0	49.0	7.4	42.9	9.3	26.6	3.8	24.1	3.9	0.40
05SMC12AD30 CM01	0.32	0.31	0.11	15.88	20.50	0.13	0.06	1.12	0.04	0.04	4.86	1.86	1.80	2.82	0.88	0.56	0.18	0.16	16.05	6.99	3.07	0.14	299	705	55.0	217	44.2	12.3	52.2	8.0	47.7	10.2	29.5	4.3	27.3	4.4	0.77
05SMC12AD30 CM02	0.33	0.47	0.13	14.87	21.80	0.11	0.08	1.25	0.04	0.04	4.68	2.26	1.66	2.76	1.22	0.54	0.26	0.14	15.85	6.93	2.85	0.21	242	607	46.5	186	38.0	10.6	45.5	7.0	40.0	8.6	24.1	3.5	22.0	3.5	0.68
05SMC12AD30 CM03	0.40	0.34	0.09	16.27	21.10	0.13	0.06	1.04	0.06	0.05	3.58	1.60	1.94	3.12	0.96	0.67	0.18	0.17	17.15	7.08	3.56	0.11	325	733	57.9	238	45.0	12.9	58.4	9.0	51.5	12.0	33.6	5.0	30.4	4.9	0.77
05SMC13AD15 CM01	0.29	0.29	0.11	14.52	21.40	0.13	0.06	1.00	0.04	0.04	5.07	2.24	1.90	2.84	0.92	0.65	0.17	0.16	15.95	6.28	3.71	0.19	253	638	47.8	192	38.4	10.7	45.3	7.0	39.8	8.4	24.1	3.4	21.4	3.5	0.68
Standard JMn-1	0.15	>10000	1.06	21.14	8.48	0.04	0.09	0.46	0.03	0.04	5.92	3.34	1.56	3.84	1.28	0.41	0.16	0.08	16.20	6.73	3.54	<0.005	134	290	33.6	134	29.8	7.9	30.9	5.0	28.7	5.7	16.0	2.2	14.6	2.2	2.49
Standard JMn-1	0.15	>10000	1.06	20.99	8.47	0.04	0.09	0.46	0.03	0.04	5.92	3.36	1.57	3.86	1.30	0.41	0.16	0.08	16.40	6.24	3.28	0.13	135	286	34.0	135	29.2	8.0	32.5	5.2	28.8	5.9	16.4	2.3	14.8	2.3	2.48
Recommended Values for JMn-1	0.17	1.26	1.11	25.63	5.04	0.04	0.11	0.64	0.03	0.04	6.60	0.04	2.08	1.04	0.39	0.12	0.17	0.08	—	7.90	—	0.11	122	277	31.4	137	30.2	7.6	29.8	4.8	28.3	5.8	14.6	2.1	13.8	2.1	5.09

nss: not sufficient sample

Table 5-6-3 Analytical Results of ALS Chemex Standard

Standard		Co	Ni	Cu	Mn	Fe	Ti	SiO2	Al	Ca	K	Na	P
		ppm			%								ppm
GEOMS-03	Results of this time	11	51	130	–	4.07	0.04	–	1.86	0.34	0.34	0.01	1020
GEOMS-03 (Recommended values*)	Lower Bound	*10*	*48*	*121*	–	3.48	*0.03*	–	*1.63*	*0.30*	*0.29*	*<0.01*	*880*
	Upper Bound	*13*	*59*	*148*	–	4.28	*0.04*	–	*2.01*	*0.38*	*0.37*	*0.03*	*1100*
SY-4	Results of this time	–	–	–	0.12	–	–	50.20	–	–	–	–	–
SY-4 (Recommended Values*)	Lower Bound	–	–	–	*0.09*	–	–	*47.40*	–	–	–	–	–
	Upper Bound	–	–	–	*0.12*	–	–	*52.40*	–	–	–	–	–

Standard		Pb	Zn	Mo	V	Ba	Sr
		ppm					
SY-4	Results of this time	15	92	3	11	320	1110
SY-4 (Recommended Values*)	Lower Bound	<5	79	<2	<5	306	1070
	Upper Bound	16	107	4	10	375	1310

Standard		La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
		ppm													
SY-4	Results of this time	60.6	124.0	14.9	54.3	12.0	2.1	13.8	2.6	18.2	4.4	14.2	2.2	14.4	2.1
SY-4 (Recommended Values*)	Lower Bound	*51.7*	*109.5*	*13.4*	*50.8*	*11.3*	*1.7*	*12.5*	*2.2*	*16.3*	*3.8*	*12.7*	*2.0*	*13.2*	*1.8*
	Upper Bound	*64.3*	*134.5*	*16.6*	*63.2*	*14.1*	*2.3*	*15.5*	*3.0*	*20.1*	*4.8*	*15.7*	*2.6*	*16.4*	*2.4*

Standard		Pt
		ppm
PGMS-6	Results of this time	0.118
PGMS-6 (Recommended Values*)	Lower Bound	*0.11*
	Upper Bound	*0.13*

Standard		H2O+	H2O-	LOI
		%		
G-2000	Results of this time	3.11	0.80	4.64
G-2000 (Recommended Values*)	Lower Bound	*2.89*	*0.70*	*4.08*
	Upper Bound	*3.35*	*0.82*	*5.00*

*: ALS Chemex LTD.

The analytical results of the manganese crust of MC12 and MC13 areas show that Mn ranges form 6.47 to 19.52% and five samples (05SMC12AD15 CM01, 05SMC12AD15 CM07, 05SMC12AD16 CM05, 05SMC12AD16 CM06 and 05SMC12AD29 CM06) have Mn values of less than 10%. While, Co ranges from 0.08 to 0.51 and only five samples of 05SMC12AD15 CM07, 05SMC12AD16 CM04, 05SMC12AD29 CM05, 05SMC12AD29 CM08 and 05SMC12AD30 CM03 have Co value of greater than 0.4%. Pt is generally not so high ranging from 0.10 to 0.61ppm with the maximum amount of 1.02ppm (05SMC12AD17 CM01. H_2O^+ is 4.88 to 8.81% and no sample shows H_2O^+ more than 10%. The highest H_2O^- value of 8.57%was obtained from sample 05SMC12AD20 CM01, but other than this H_2O^- is generally less than 5%, ranging from 1.51 to 5.09%. Ca is generally low, showing a range of 1.34 to 5.49%.

The sample described as massive goethite (05SMC12AD16CM07) has Fe50.00% and the total of all the elements other than Fe, LOI, H_2O^+ and H_2O^+ is less than 3%.

The chemical analyses were monitored using the manganese nodule standard of the geological survey of Japan (JMn-1). Comparisons of analytical results of this time and the recommended value of this do not give significant differences showing approximately 1% for major elements and few % for trace elements and REE. The standard samples prepared by ALS Chemex were analyses simultaneously with the samples of CM12 and CM13 area. Significant differences of analytical results between analyses of this time and recommended values were, also, not observed.

5-6-5 Considerations

(1) Chemical Compositions of Bulk Samples

The analytical results of manganese crust bulk samples of this year and previous year were compiled for MC12 and MC13 areas for further considering the nature of the manganese crust of these areas (Tables 5-6-4 and 5-6-5).

As shown in the histograms of key elements (Co, Ni, Pt), chemical compositions of the manganese crust do not show clear differences between MC12 and MC13 areas, most of the samples showing Co and Ni less than 0.4% and Pt less than 0.3ppm (Figure 5-6-1). Compared with the chemical compositions of typical areas of manganese crust, such as Hawaii and the Marshall Island (e.g. Usui, 1996 and Hein et al. 2000), these values are not high.

Table 5-6-4 Sampling Depth, Thickness and Chemical Composition of Manganese Crust (Majour Elements, includes 1998 samples)

Sampling No.	Code	Crust Type	Substrate	Condition of Surface	Analyzed Part	Water depth (m)	Tickness (cm)	Co (%)	Ni (%)	Cu (%)	Mn (%)	Fe (%)	Mn/Fe	Pb (%)	Zn (%)	Ti (%)	Mo (%)	V (%)	Si (%)	Al (%)	Ca (%)	Na (%)	K (%)	P (%)	Ba (%)	Sr (%)	LOI (%)	H_2O+ (%)	H_2O- (%)
MC12-area																													
98SMC12AD03 CM01	A	cobble	limestone	botryoidal	bulk	1,903	10	0.27	0.29	<0.001	16.58	18.60	0.89	0.09	0.06	1.23	0.042	0.055	3.75	1.14	3.57			0.72					
98SMC12AD05 CM01	A	cobble	limestone	botryoidal	f	1,218	3	0.58	0.34	<0.001	20.26	17.72	1.14	0.15	0.07	1.16	0.053	0.066	1.85	0.59	8.89			2.65					
98SMC12AD06 CM03	B	crust	hyaloclastite	botryoidal	bulk	2,474	14	0.17	0.15	<0.001	14.26	26.54	0.54	0.08	0.10	2.05	0.030	0.073	7.19	2.10	1.76			0.35					
98SMC12AD07 CM01	A	fragment	-	smooth	bulk	2,159	6+	0.27	0.21	<0.001	16.20	22.95	0.71	0.10	0.11	2.12	0.024	0.069	5.60	1.50	2.09			0.28					
98SMC12AD08 CM01	A	crust	tuff	botryoidal	bulk	1,736	5	0.94	0.35	0.02	21.18	21.88	0.97	0.12	0.09	1.44	0.049	0.072	3.63	1.33	2.13			0.28					
98SMC12AD09 CM01	A	cobble	reef limestone	smooth	bulk	1,106	2	0.52	0.34	<0.001	23.70	16.57	1.43	0.16	0.07	1.06	0.056	0.076	1.67	0.52	4.89			0.89					
98SMC12AD13 CM01	A	crust	limestone	botryoidal	bulk	2,309	0.3	0.36	0.32	0.01	20.40	19.00	1.07	0.11	0.05	0.74	0.038	0.055	4.97	1.05	3.80			0.65					
98SMC12AD14 CM01	A	crust	basalt	botryoidal	bulk	2,289	4.5	0.40	0.29	<0.001	19.49	17.95	1.09	0.11	0.06	1.38	0.040	0.050	4.46	1.18	2.21			0.28					
98SMC12AD14 CM04	C	crust		botryoidal	bulk	2,289	6.5	0.17	0.15	<0.001	14.58	25.21	0.58	0.08	0.09	1.95	0.025	0.061	6.66	1.92	1.81			0.28					
05SMC12AD15 CM01	a1	crust	volcaniclastic rock	coke-like	bulk	2,437	7	0.12	0.13	0.11	7.04	21.80	0.32	0.04	0.06	1.45	0.01	0.05	9.82	6.36	1.84	4.06	2.22	0.44	0.16	0.10	13.35	6.81	3.09
05SMC12AD15 CM02	a2	crust	volcaniclastic rock?	botryoidal, coke-like	bulk	2,437	8	0.25	0.20	0.14	10.80	22.90	0.47	0.07	0.06	1.45	0.02	0.04	6.62	3.88	1.35	3.28	1.22	0.52	0.18	0.13	14.95	7.34	3.42
05SMC12AD15 CM03	a3	crust	-	botryoidal, coke-like	bulk	2,437	14+	0.22	0.20	0.10	11.62	23.30	0.50	0.08	0.07	1.45	0.04	0.04	5.71	2.80	1.50	2.88	0.96	0.59	0.21	0.15	14.85	6.79	1.65
05SMC12AD16 CM01	a1	crust	calcareous conglomerate	botryoidal	bulk	2,004	8	0.24	0.19	0.06	11.81	25.00	0.47	0.10	0.07	1.68	0.03	0.05	5.03	2.12	2.22	2.64	0.82	0.78	0.23	0.16	15.05	6.79	4.26
05SMC12AD16 CM02	a2	crust	-	botryoidal	bulk	2,004	11+	0.21	0.19	0.08	10.84	23.00	0.47	0.08	0.06	0.21	0.03	0.04	5.54	3.08	4.14	2.90	1.02	0.85	0.17	0.14	14.65	6.48	3.53
05SMC12AD16 CM03	a3	crust	-	botryoidal	bulk	2,004	11+	0.26	0.19	0.07	11.31	23.50	0.48	0.09	0.06	1.67	0.03	0.05	6.06	3.16	2.56	3.04	1.02	0.66	0.21	0.15	15.40	7.19	3.99
05SMC12AD17 CM01	a1	fragment	-	coke-like	bulk	1,772	4+	0.69	0.31	0.08	15.88	22.50	0.71	0.13	0.04	1.36	0.03	0.05	3.16	1.80	3.00	3.52	1.00	0.59	0.18	0.15	18.65	6.86	4.31
05SMC12AD19 CM01	a2	fragment	-	botryoidal	bulk	1,873	7+	0.31	0.24	0.08	12.86	26.90	0.48	0.11	0.06	1.35	0.03	0.04	4.91	1.90	1.60	2.66	0.84	0.58	0.21	0.15	15.15	7.97	2.54
05SMC12AD19 CM02	a3	crust	sandstone	botryoidal	bulk	1,873	3	0.29	0.24	0.08	12.97	24.00	0.54	0.13	0.07	1.36	0.03	0.04	5.71	2.22	1.56	2.78	0.88	0.55	0.23	0.16	14.65	6.55	4.27
05SMC12AD20 CM01	a1	crust	calcareous conglomerate	botryoidal	bulk	1,562	0.5	nss	nss	nss	19.52	nss	-	0.15	0.05	nss	0.06	0.06	2.17	nss	nss	nss	nss	nss	0.11	0.17	18.20	6.29	8.57
05SMC12AD22 CM01	a1	fragment	-	coke-like	bulk	1,822	3.5+	0.76	0.32	0.11	17.35	21.70	0.80	0.14	0.05	1.35	0.04	0.04	2.71	1.32	2.08	3.62	0.94	0.57	0.20	0.17	17.90	8.73	3.85
05SMC12AD28 CM01	a1	crust	calcareous conglomerate	botryoidal	bulk	1,858	1	0.22	0.18	0.11	10.57	24.10	0.44	0.12	0.07	2.05	0.02	0.05	7.15	3.12	1.53	2.84	1.02	0.47	0.22	0.14	13.00	6.75	2.99
05SMC12AD29 CM01	a1	crust	calcareous conglomerate	botryoidal, granule	bulk	2,385	5	0.34	0.29	0.10	14.37	21.70	0.66	0.13	0.06	1.32	0.04	0.05	4.72	1.86	1.87	2.88	0.90	0.57	0.19	0.16	15.50	6.58	4.67
05SMC12AD29 CM02	a2	crust	calcareous sandstone	botryoidal	bulk	2,385	3.5	0.34	0.30	0.11	16.03	21.60	0.74	0.13	0.06	1.20	0.05	0.04	4.49	1.66	1.87	2.90	0.86	0.61	0.20	0.17	16.35	6.87	6.12
05SMC12AD29 CM03	a3	cobble	-	coke-like	bulk	2,385	14+	0.28	0.25	0.12	12.74	23.60	0.54	0.09	0.06	1.33	0.04	0.04	5.14	2.70	1.66	3.24	0.96	0.62	0.20	0.15	15.45	4.88	4.56
05SMC12AD29 CM07	a4	crust	-	coke-like	bulk	2,385	10+	0.39	0.25	0.15	12.90	23.10	0.56	0.10	0.05	1.52	0.03	0.04	4.82	2.98	2.14	3.26	1.18	0.50	0.19	0.15	16.55	6.99	5.09
05SMC12AD30 CM01	a1	crust	siltstone	botryoidal	bulk	2,370	3	0.32	0.31	0.11	15.88	20.50	0.77	0.13	0.06	1.12	0.04	0.04	4.86	1.86	1.80	2.82	0.88	0.56	0.18	0.16	16.05	6.99	3.07
05SMC12AD30 CM02	a2	cobble	siltstone	granule	bulk (upper surface)	2,370	1	0.33	0.47	0.13	14.87	21.80	0.68	0.11	0.08	1.25	0.04	0.04	4.68	2.26	1.66	2.76	1.22	0.54	0.26	0.14	15.85	6.93	2.85
MC13-area																													
98SMC13AD02 CM02	B	crust	mudstone	botryoidal	bulk	2,299	1.5	0.25	0.24	0.08	14.82	20.96	0.71	0.09	0.10	1.58	0.022	0.049	9.11	2.80	2.69			0.45					
98SMC13AD03 CM01	A	cobble	phosphorite	botryoidal	bulk	1,750	9	0.29	0.24	<0.001	16.46	21.27	0.77	0.09	0.08	1.59	0.024	0.052	6.24	1.79	2.99			0.27					
98SMC13AD05 CM01	C	fragment	-	granule	bulk	2,798	1.5+	0.05	0.06	<0.001	6.80	11.62	0.59	0.02	0.03	0.94	0.006	0.031	19.63	6.63	6.91			0.18					
98SMC13AD06 CM09	C	cobble	limestone	granule	bulk	2,347	5	0.39	0.29	0.03	18.24	23.10	0.79	0.12	0.08	1.40	0.041	0.064	5.39	1.45	2.01			0.35					
98SMC13AD06 CM17	E	crust	conglomerate	granule	bulk	2,347	5	0.49	0.36	0.03	21.23	19.22	1.10	0.14	0.07	0.96	0.052	0.069	3.99	0.81	2.38			0.26					
98SMC13AD07 CM01	A	cobble	limestone	botryoidal	bulk	2,043	3.5	0.33	0.28	<0.001	16.67	18.82	0.89	0.11	0.09	1.42	0.031	0.051	5.88	1.63	2.07			0.24					
98SMC13AD08 CM02	F	cobble	conglomerate	granule	bulk	2,499	1	0.52	0.43	0.05	22.00	20.48	1.07	0.13	0.08	0.96	0.047	0.061	4.70	1.15	2.54			0.36					
98SMC13AD12 CM15	M	cobble	-	granule	bulk	1,975	10+	0.33	0.29	0.01	16.60	24.54	0.68	0.10	0.09	1.68	0.030	0.059	6.88	1.99	1.99			0.34					
98SMC13AD13 CM01	A	crust	basalt	granule	bulk	2,458	0.15	0.45	0.37	<0.001	20.37	21.31	0.96	0.13	0.06	1.15	0.027	0.056	4.83	1.04	3.31			0.30					
05SMC13AD15 CM01	a1	crust	siltstone	botryoidal	bulk	1,724	1	0.29	0.29	0.11	14.52	21.40	0.68	0.13	0.06	1.00	0.04	0.04	5.07	2.24	1.90	2.84	0.92	0.65	0.17	0.16	15.95	6.28	3.71

Table 5-6-5 Sampling Depth, Thickness and Chemical Composition of Manganese Crust (Pt and REE, includes 1998 samples)

Sampling No.	Code	Crust Type	Substrate	Condition of Surface	Analyzed Part	Water depth (m)	Tickness (cm)	Pt (ppm)	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)	Lu (ppm)
MC12-area																						
98SMC12AD03 CM01	A	cobble	limestone	botryoidal	bulk	1,903	10	0.21	259	462	44.5	194	37	9.59	36	6.5	38	7.5	22	3.24	19	2.88
98SMC12AD05 CM01	A	cobble	limestone	botryoidal	bulk	1,218	3	0.41	309	758	49.2	219	43	10.60	37	7.5	45	9.1	27	4.05	23	3.77
98SMC12AD06 CM03	B	crust	hyaloclastite	botryoidal	bulk	2,474	14	0.18	310	548	53.6	237	48	12.20	45	8.3	50	9.7	29	4.25	25	3.82
98SMC12AD07 CM01	A	fragment	-	smooth	bulk	2,159	6+	0.32	350	623	61.3	271	55	14.00	52	9.6	57	11.0	33	4.87	28	4.47
98SMC12AD08 CM01	A	crust	tuff	botryoidal	bulk	1,736	5	0.67	318	708	47.5	210	41	10.30	35	7.0	41	8.1	25	3.70	22	3.63
98SMC12AD09 CM01	A	cobble	reef limestone	smooth	bulk	1,106	2	0.30	318	905	51.0	225	45	10.90	37	7.6	43	8.5	26	3.90	22	3.55
98SMC12AD13 CM01	A	crust	limestone	botryoidal	bulk	2,309	0.3	0.16	302	621	54.4	245	51	12.80	47	8.5	50	9.8	29	4.22	26	4.06
98SMC12AD14 CM01	A	crust	basalt	botryoidal	bulk	2,289	4.5	0.20	283	707	49.2	231	51	12.70	45	8.6	49	10.0	30	4.90	29	4.66
98SMC12AD14 CM04	C	crust		botryoidal	bulk	2,289	6.5	0.30	276	494	46.0	207	42	10.80	40	7.4	45	8.8	26	3.90	23	3.62
05SMC12AD15 CM01	a1	crust	volcaniclastic rock	coke-like	bulk	2,437	7	0.18	152.0	281.0	27.9	112.0	22.9	6.6	28.4	4.4	26.2	5.8	16.4	2.4	15.00	2.40
05SMC12AD15 CM02	a2	crust	volcaniclastic rock?	botryoidal, coke-like	bulk	2,437	8	0.35	271.0	530.0	46.6	186.0	37.3	10.6	45.6	6.9	41.8	9.1	26.2	3.8	24.50	3.90
05SMC12AD15 CM03	a3	crust	-	botryoidal, coke-like	bulk	2,437	14+	0.12	303.0	551.0	57.6	233.0	45.9	12.8	55.4	8.7	48.8	10.6	29.6	4.3	26.00	4.00
05SMC12AD16 CM01	a1	crust	calcareous conglomerate	botryoidal	bulk	2,004	8	0.12	290.0	661.0	52.0	208.0	41.9	11.8	50.9	7.9	47.3	10.3	28.9	4.2	25.60	4.00
05SMC12AD16 CM02	a2	crust	-	botryoidal	bulk	2,004	11+	0.11	244.0	465.0	41.6	171.5	33.5	10	43.3	6.7	40.7	9	26.3	3.8	23.70	3.80
05SMC12AD16 CM03	a3	crust	-	botryoidal	bulk	2,004	11+	0.14	263.0	599.0	48.0	194.5	38.9	10.8	46.9	7.4	41.7	9.6	25.6	3.9	23.00	3.70
05SMC12AD17 CM01	a1	fragment	-	coke-like	bulk	1,772	4+	1.02	289.0	1135.0	44.8	180.5	35.9	10.1	44	6.7	40.5	9.2	26.9	3.9	25.00	4.10
05SMC12AD19 CM01	a2	fragment	-	botryoidal	bulk	1,873	7+	0.19	276.0	709.0	48.5	199.5	39.7	11.2	48.8	7.6	45.1	9.9	28.1	4	25.20	4.00
05SMC12AD19 CM02	a3	crust	sandstone	botryoidal	bulk	1,873	3	0.16	257.0	846.0	44.5	179.0	36.9	10.4	43.1	6.6	40.4	8.4	25.1	3.5	22.80	3.50
05SMC12AD20 CM01	a1	crust	calcareous conglomerate	botryoidal	bulk	1,562	0.5	0.19	322.0	741.0	59.4	244.0	48.0	13.2	58	9	51.8	11.8	33.4	4.9	30.30	4.90
05SMC12AD22 CM01	a1	fragment	-	coke-like	bulk	1,822	3.5+	1.28	320.0	1295.0	52.0	207.0	41.3	11.2	48.7	7.3	43.7	9.9	29.2	4.2	27.00	4.30
05SMC12AD28 CM01	a1	crust	calcareous conglomerate	botryoidal	bulk	1,858	1	nss	192.0	712.0	35.4	139.5	29.3	8.4	34.7	5.3	31.6	6.6	18.9	2.7	17.20	2.70
05SMC12AD29 CM01	a1	crust	calcareous conglomerate	botryoidal, granule	bulk	2,385	5	0.12	304.0	721.0	58.7	234.0	45.0	12.6	54.4	8.4	49.7	10.4	29.9	4.2	26.80	4.20
05SMC12AD29 CM02	a2	crust	calcareous sandstone	botryoidal	bulk	2,385	3.5	0.13	306.0	752.0	59.0	233.0	46.7	13	54.2	8.4	49.2	10	29.5	4.1	26.10	4.00
05SMC12AD29 CM03	a3	cobble	-	coke-like	bulk	2,385	14+	0.32	327.0	611.0	58.3	236.0	47.4	13.4	58.6	9.1	51.5	11.5	32.2	4.7	28.80	4.70
05SMC12AD29 CM07	a4	crust	-	coke-like	bulk	2,385	10+	0.56	303.0	789.0	51.4	204.0	41.6	11.6	49.1	7.5	45.2	9.7	28.3	4.1	25.90	4.30
05SMC12AD30 CM01	a1	crust	siltstone	botryoidal	bulk	2,370	3	0.14	299.0	705.0	55.0	217.0	44.2	12.3	52.2	8	47.7	10.2	29.5	4.3	27.30	4.40
05SMC12AD30 CM02	a2	cobble	siltstone	granule	bulk (upper surface)	2,370	1	0.21	242.0	607.0	46.5	186.0	38.0	10.6	45.5	7	40	8.6	24.1	3.5	22.00	3.50
MC13-area																						
98SMC13AD02 CM02	B	crust	mudstone	botryoidal	bulk	2,299	1.5	0.15	223	505	39.1	173	36	8.91	32	6.2	37	7.1	21	3.25	19	3.14
98SMC13AD03 CM01	A	cobble	phosphorite	botryoidal	bulk	1,750	9	0.21	232	465	40.3	178	36	9.22	34	6.2	37	7.3	22	3.30	19	3.15
98SMC13AD05 CM01	C	fragment	-	granule	bulk	2,798	1.5+	0.03	51	109	10.3	48	11	3.03	10	1.9	11	2.1	6	0.94	5.6	0.88
98SMC13AD06 CM09	C	cobble	limestone	granule	bulk	2,347	5	0.21	302	629	52.3	231	47	11.90	43	8.1	49	9.9	29	4.40	26	4.12
98SMC13AD06 CM17	E	crust	conglomerate	granule	bulk	2,347	5	0.08	315	627	53.1	241	49	12.30	46	8.8	54	11.0	32	4.92	29	4.60
98SMC13AD07 CM01	A	cobble	limestone	botryoidal	bulk	2,043	3.5	0.14	237	517	40.7	181	37	9.33	34	6.5	38	7.6	23	3.49	21	3.32
98SMC13AD08 CM02	F	cobble	conglomerate	granule	bulk	2,499	1	0.16	292	609	61.2	261	53	13.80	53	9.0	54	11.0	32	4.75	30	4.61
98SMC13AD12 CM15	M	cobble	-	granule	bulk	1,975	10+	0.26	290	599	51.3	221	44	11.20	43	7.5	46	9.7	28	4.18	25	3.98
98SMC13AD13 CM01	A	crust	basalt	granule	bulk	2,458	0.15	0.16	373	1042	76.7	335	69	17.20	59	11.0	62	12.0	35	5.04	30	4.62
05SMC13AD15 CM01	a1	crust	siltstone	botryoidal	bulk	1,724	1	0.19	253.0	638.0	47.8	191.5	38.4	10.7	45.3	7	39.8	8.4	24.1	3.4	21.40	3.50

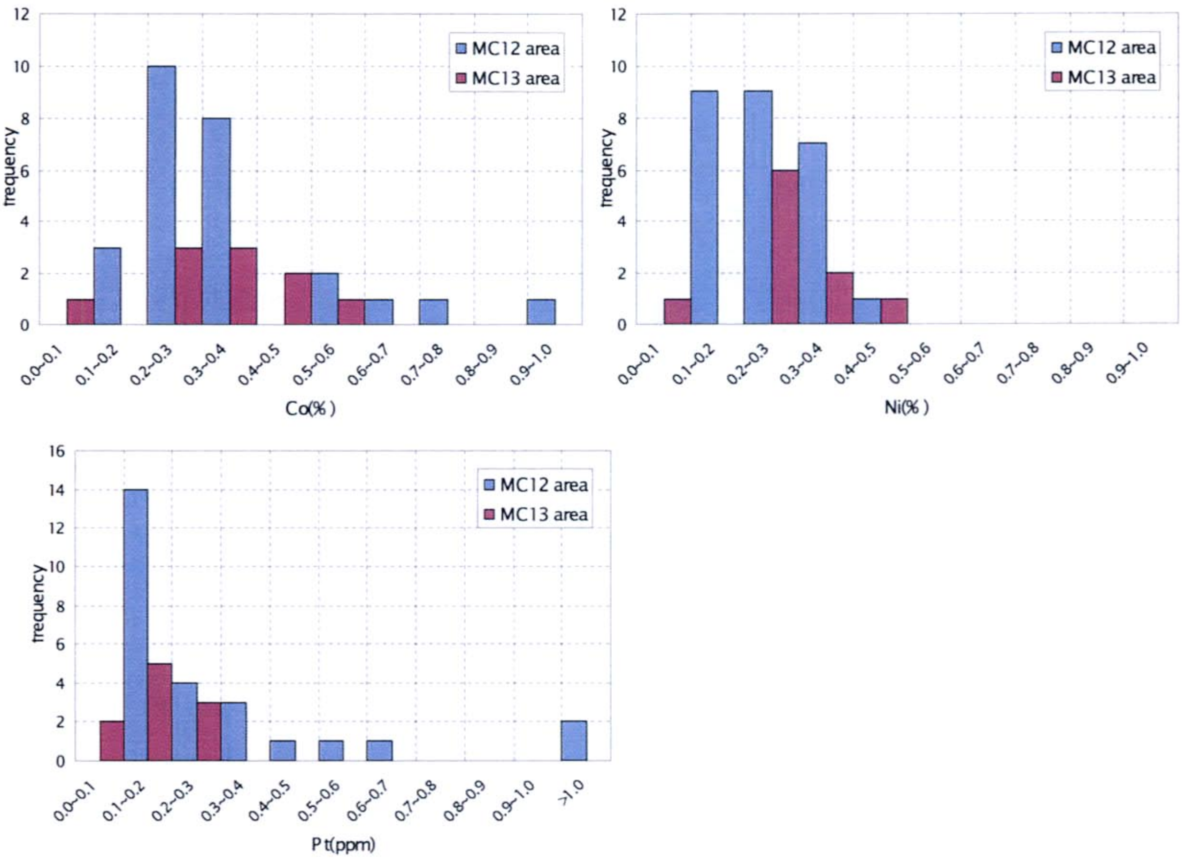


Figure 5-6-1 Histograms of Co, Ni and Pt

Although the grades of the manganese crust in MC12 and MC13 areas are slightly low compared with other typical area elsewhere, samples with relatively high Co (more than 0.5%) and Pt (more than 0.5ppm) are found in MC12 area. They are six samples of 98SMC12AD05 CM01, 98SMC12AD08 CM01, 98SMC12AD09 CM01, 05SMC12 AD17 CM01, 05SMC12 AD22 CM01 and 05SMC12AD29 CM07. Paying attention to the appearances of these six samples, these samples are divides into two groups of common occurrences. The two samples of manganese crust show compact texture and they occur approximately at 1,200m deep, being attached to substrate of reef limestone. The thickness of manganese crust of them is 2 to 3cm. The common features of rest of the four samples are porous columnar texture without fillings. Three of them were collected approximately at 1,800m deep and one samples was collected at slightly deeper depth of 2,400m.

The two samples collected approximately at 1,800m show very high Pt content of more than 1ppm. Although it is not clear, because some of them are incomplete samples, the thickness of these manganese crusts are 5 to 10cm thick. Based on the appearances and occurrences of the manganese crust, Co and Pt might have been concentrated on the surface of manganese crust through adsorption by manganese oxides (vernadite).

To understand chemical nature of the manganese crust, the analytical results are plotted on diagrams of (Cu+Ni)x10-Fe-Mn (Figure 5-6-2) and chondrite normalized patterns (Figure 5-6-3). The chondrite composition of Wakita et al. (1971) was used for normalization (Table 5-6-6).

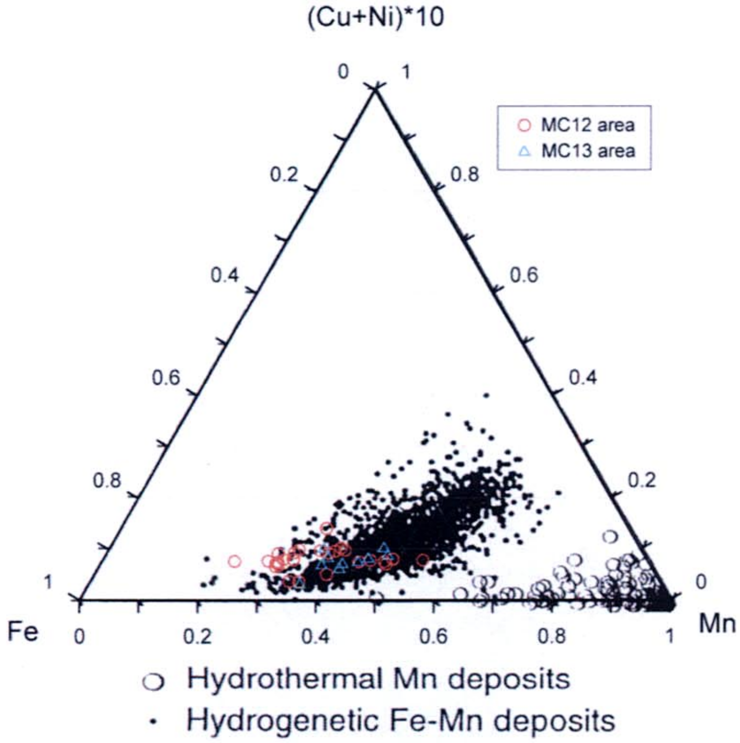


Figure 5-6-2 (Cu+Ni)x10-Fe—Ni Diagram

(Plotted on the dioagram of Usui and Someya, 1997.)

On the (Cu+Ni)x10-Fe-Mn diagram (Figure 5-6-2), all of the manganese crust of MC12 and MC13 areas are plotted within a field of hydrogenetic manganese crust by Usui and Someya (1997) and they are slightly Fe enriched compared to Mn, occupying the area away from the field of manganese oxide of diagenetic origin. Some of chondrite normalized patterns of MC12 and MC13 areas show Ce positive anomaly, a characteristic feature of hydrogenetic manganese oxides. The chemical characteristics of these, coincide with occurrences of vernadite shown by the microscopic work and X-ray diffraction analyses, suggest hydrogenetic origin for manganese crust of MC12 and MC13 areas.

For MC12 area, calculation of correlation coefficients and no-correlation test were conducted for major elements, Pt, La and Ce of REE, sampling depth and thickness of manganese crust (Table 5-6-7). The main characteristics of these are given below.