NO.

REPORT
ON
THE COOPERATIVE STUDY PROJECT
ON THE DEEPSEA MINERAL RESOURCES
IN SELECTED OFFSHORE AREAS OF THE SOPAC REGION
(VOLUME 3)
SEA AREA OF THE REPUBLIC
OF THE MARSHALL ISLANDS

MARCH 2003

METAL MINING AGENCY OF JAPAN

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

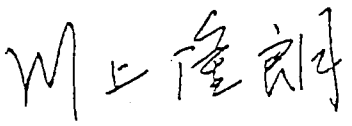
In response to a request by the South Pacific Applied Geoscience Commission (SOPAC), the Government of Japan has undertaken marine geological and other studies relating to mineral prospecting to assess the mineral resources potential of the deep sea bottom in the offshore regions of SOPAC member countries.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

The survey is planned to be undertaken as Stage 2, Phase 1 project starting from Fiscal 2000. This is the third year of the project, and the target area is the exclusive economic zone of the Republic of the Marshall Islands. MMAJ dispatched the Hakurei Maru No.2, a research vessel fitted for investigating deep sea mineral resources, to the survey area for thirty seven days from June 4, 2002 to July 10, 2002, successfully completing the survey as planned with the cooperation of the government of the Republic of the Marshall Islands.

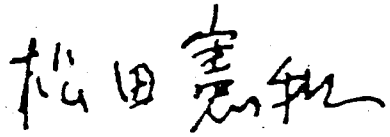
The present report sums up the results of this third year survey in the exclusive economic zone of the Republic of the Marshall Islands.

We wish to extend our sincere gratitude to all persons concerned, particularly to the staff of the SOPAC Secretariat, Government of the Republic of the Marshall Islands, as well as the Japanese Ministry of Foreign Affairs, the Ministry of Economy, Trade and Industry and the Japanese Embassy in the Republic of the Marshall Islands.

March, 2003



Takao Kawakami
President
Japan International Cooperation Agency



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ABSTRACT

The cooperative study project on the Deepsea Mineral Resources in the selected offshore areas of the South Pacific Applied Geoscience Commission(SOPAC) member countries has started as the Stage2, Phase 1 project in fiscal year 2000. This year is the third year of the program and the survey was carried out from June 4, 2002 to July 10, 2002, in the Exclusive Economic Zone (EEZ) of the Republic of the Marshall Islands, with total date for the survey of 37 days aiming at the survey of cobalt-rich manganese crust (cobalt crust).

The survey of the cobalt crust of the Republic of the Marshall Islands was carried out in1996 and 1998, and at the thirteen seamounts, seafloor topographic maps and acoustic reflection intensity distribution images by MBES were obtained, and the collection of samples by dredging was conducted. In this year on the basis of the previous results, three seamounts, MS01, MS11, and MS12 were selected and drilling by BMS (deep sea boring system) was conducted to understand the occurrence of cobalt crust. At the same time, environmental survey was carried out to make clear the environmental characteristics of the area.

As the result of the survey of this year, average thickness of the cobalt crust of three seamounts, MS01, MS11, and MS12 were obtained to be 59mm, 132mm, and 70mm. This result is thicker compared with the thickness previously obtained but the average grade of Co of each seamounts were, 0.44%, 0.34%, and 0.46%, lower compared with that of previous results. The inferred resources of three seamounts are, in the order of abundance, 173.2 million ton, 55.5 million ton and 32.8 million ton, for seamounts MS11, MS01 and MS12, respectively. There were some cases that the thickness of cobalt crust may be affected by overlying unconsolidated sediments. If so, this will give significant effect for the resource assessment of cobalt crust, and more detailed survey is necessary to confirm this relation.

An environmental survey was conducted to evaluate the potential magnitude of mining impacts in the deep-sea environment by investigating the distributions of benthic organisms and properties of sediments. The survey was conducted in three seamounts of MS01, MS11 and MS12.

General trends in the results from the three seamounts indicate that the abundance of metazoan meiobenthos decreases with increasing water depth. High concentrations of surface nematodes were remarkable in the vertical distributions. The abundance of metazoan macrobenthos decreases with increasing water depth as it does in the meiobenthos, and their high concentrations were remarkable in the surface layer. In the vertical distributions of the sediment properties, concentrations of the total organic carbon and the total nitrogen decreased with increasing sediment depth at some stations. The abundance of benthic organisms is mainly controlled by the quantity of available organic matter. This is supported by the finding in this study that benthic

organisms decreased in abundance from the top of seamounts to the slope sites. This is because the quantities of organic matter, which reflect the feeding conditions of benthic organisms, are likely to accumulate at the top of a seamount and not on the seamount slopes. Then, there were differences in the abundances of benthic organisms in each seamount area. It is also reasonable to assume that differences in topography influence heterogeneity in feeding conditions for the benthic organisms.

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Chapter 1 Outline of the Survey

1-1 Survey Title

The Cooperative Study on the Deepsea Mineral Resources in Selected Offshore Areas of the SOPAC Region, 2002

－Sea Area of the of the Republic of the Marshall Islands－

1-2 Purpose of the Survey

The purpose of the survey lies in the assessment of the potential of cobalt rich manganese crust (cobalt crust) resources and the environmental characteristic within the Exclusive Economic Zone (EEZ) of the Republic of the Marshall Islands, a member country of SOPAC.

1-3 Survey Area

The survey area for fiscal year 2002 is the sea area by joining the following coordinates, a to d (Figures 1-3-1). The area was selected in accordance with the joint study program for deepsea mineral resources in the EEZ of the SOPAC member countries agreed upon by the Japanese executing agency and the South Pacific Applied Geoscience Commission (SOPAC) on March 3, 2000.

	Latitude	Longitude
a.	20° 20' S	155° 00' E
b.	20° 00' S	175° 00' E
c.	5° 00' S	175° 00' E
d.	5° 00' S	155° 00' E
a.	20° 00' S	155° 00' E

1 - 4 Duration of the Survey

Survey cruising: June 4, 2002 to July 10, 2002

Analysis and other works: April 1, 2002 to March 31, 2003

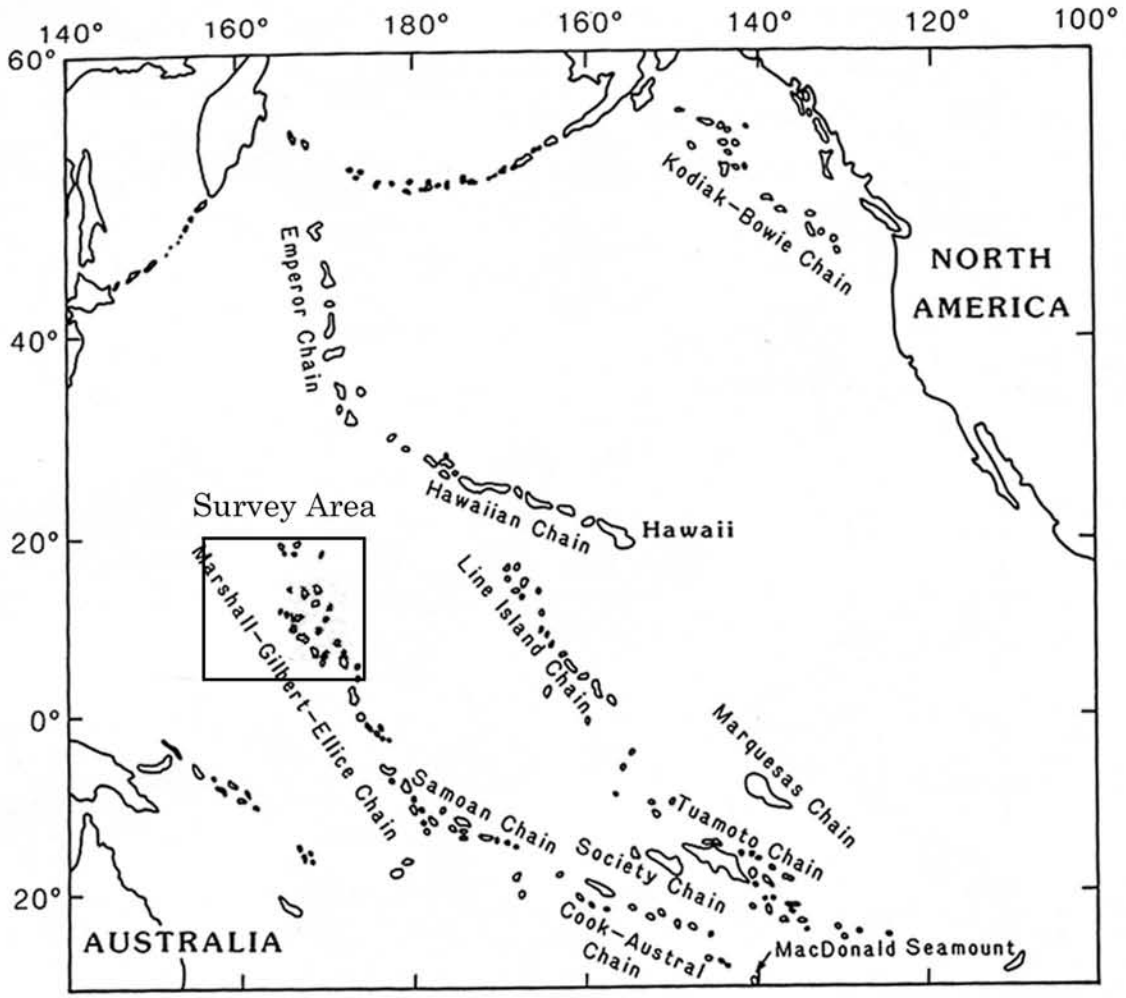


Figure 1-3-1 Location Map of the Syrvey Area

1 - 5 Survey Participants

Japanese participants

Field supervisor	Akira USUI	
	(National Institute of Advanced Industrial Science and Technology)	

Members

Leader	Katsutoki MATSUMOTO	
	(Deep Ocean Resources Development Co., Ltd.:DORD)	
	Nadao SAITO	(DORD)
	Akinori UCHIYAMA	(DORD)
	Norikiyo SUGIURA	(DORD)
	Masatsugu OKAZAKI	(DORD)
	Nobuhiro GOTO	(DORD)
	Hideto BABA	(DORD)
	Saburo TACHIKAWA	(DORD)
	Gen MURANO	
	(Marine Biological Research Institute of Japan Co., Ltd.)	
	Tateki YOSHIDA	
	(Ocean Engineering & Development Co.,Ltd.:OED)	
	Masaaki KIKUCHI	(OED)
	Shigenobu MARUYAMA	(OED)
	Masahiro HAMAZAKI	(OED)
	Takafumi TOMINAGA	(OED)
	Noboru ICHINOSE	(OED)
	Seiji IWASAKI	(OED)
	Susumu KANZAKI	(OED)

Consigned Participants

SOPAC Secretariat	Nobuyuki OKAMOTO (JICA Expert)
Trainee	Terry KEJU (Republic of the Marshall Islands)

1 - 6 Survey Achievements

Survey operations were accomplished as shown in Table 1-6-1 according to the schedule given in Table 1-6-2.

Table 1-6-1 Survey Achievements

Survey Schedule				
Depart from Majuro	June 6	16:00		
Arrive at MS12	June 9	6:00		
Start survey	June 9	8:00		
Finish survey	July 2	9:00		
Leave MS01	July 2	9:15		
Arrive at Funabashi (Japan)	July 10	9:00		
Total days of survey	24 days			

Survey Area		3 seamounts		MS01	MS11	MS12
Number of Sampling Sites						
LC		34	sites	1	9	24
BMS		52	sites	16	11	25
MC		11	sites	4	4	3
Total		97	sites	21	24	52
CTD Measurements						
Available TD sites		3	sites	1	1	1
Available CTD sites		45	sites	5	13	27
Acoustic Sounding						
NBS	30.0kHz	22.6	nm	18.5	4.1	—
nSBP	3.5kHz	22.6	nm	18.5	4.1	—
MBES	15.5kHz	2,179.7	nm	973.9	545.5	660.3
Data Processing						
MBES CDR		1 CDR bathymetric map				
Drawings		Track line Map, Bathymetric map, Acoustic reflection map etc.				

Table 1-6-2 Records of Survey Schedule 1/2

Days		Date		Area	Survey Work	Bathymetric Survey (Total of each area)	Remarks
1		6/4	Tu				Staying at Majuro
2		6/5	We				Staying at Majuro
3		6/6	Th				16:00 Depart from Majuro
4		6/7	Fr		Sailing		Sail to MS12
5		6/8	Sa		Sailing		Sail to MS12
6	1	6/9	Su	MS12	LC sampling 6 sites MS12LC19、20、21、22、 23、24	123.7nm	06:00 Arrive in MS12
7	2	6/10	Mo	MS12	LC sampling 5 sites MS12LC25、26、27、28、29 MC sampling 1site MS12MC01	105.8nm (229.5nm)	
8	3	6/11	Tu	MS12	BMS sampling 6 holes MS12BMS01A,B,C MS12BMS02A,B,C	82.3nm (311.8nm)	
9	4	6/12	We	MS12	BMS sampling 6 holes MS12BMS03A,B,C MS12BMS04A,B,C	87.2nm (399.0nm)	
10	5	6/13	Th	MS12	BMS sampling 6 holes MS12BMS05A,B,C,D,E,F	53.6nm (452.6nm)	
11	6	6/14	Fr	MS12	LC sampling 5 sites MS12LC30,31,32,33 MC sampling 1site MS12MC02,03	74.1nm (526.7nm)	
12	7	6/15	Sa	MS12	BMS sampling 7 holes MS12BMS06A,B,C MS12BMS07A,B,C、D	42.5nm (569.2nm)	
13	8	6/16	Su	MS12	Lc sampling 6 sites MS12LC34,35,36,37,38,39	91.1nm (660.3nm)	
14	9	6/17	Mo	MS12	LC sampling 3 sites MS12LC40,41,42		13:00 Leave from MS12 Sail to MS11
15	10	6/18	Tu	MS11	LC sampling 1 site MS11LC14 (CTD) MC sampling 4 sites MS12MC01,02,03、04	101.4nm	04:00 Arrive in MS11
16	11	6/19	We	MS11	LC sampling 4 sites MS11LC15,16,17,18 Acoustic Sounding	108.4nm (209.8nm)	
17	12	6/20	Th	MS11	LC sampling 4 sites MS11LC19,20,21,22 Acoustic Sounding	113. 3nm (323. 1nm)	

Table 1-6-2 Records of Survey Schedule 2/2

Days		Date		Area	Survey Work	Bathymetric Survey (Total of each area)	Remarks
18	13	6/21	Fr	MS11	BMS sampling 6 holes MS11BMS01A,B,C,D MS11BMS02A,B	99. 3nm (422. 4nm)	
19	14	6/22	Sa	MS11		123. 1nm (545. 5nm)	
20	15	6/23	Su	MS11	BMS sampling 5 holes MS11BMS03A,B,C MS11BMS04A,B		21:00 Leave from MS11 Sail to MS01
21	16	6/24	Mo		Sailing		Sail to MS01
22	17	6/25	Tu	MS01	LC sampling 1site MS01LC15（CTD） BMS sampling 6 holes MS01BMS01A,B,C MS01BMS02A,B,C	90. 4nm	07:00 Arrive in MS01
23	18	6/26	We	MS01	BMS sampling 7 holes MS01BMS03A,B,C,D MS01BMS04A,B,C	110.8nm (201. 2nm)	
24	19	6/27	Th	MS01	BMS sampling 3 holes MS01BMS05A,B,C MC sampling 4 sites MS01MC01,02、03、04	93. 6nm (294. 8nm)	
25	20	6/28	Fr	MS01	Bathymetric Survey	159. 1nm (453. 9nm)	Bad Weather
26	21	6/29	Sa	MS01	Bathymetric Survey	174. 8nm (628. 7nm)	Bad Weather
27	22	6/30	Su	MS01	Bathymetric Survey	151. 0nm (779. 7nm)	Bad Weather
28	23	7/1	Mo	MS01	Bathymetric Survey	140. 8nm (920. 5nm)	Bad Weather
29	24	7/2	Tu	MS01	Bathymetric Survey	53. 4nm (973. 9nm)	Bad Weather 09:15 Leave from MS01
30		7/3	We		Sailing		
31		7/4	Th		Sailing		
32		7/5	FR		Sailing		
33		7/6	Sa		Sailing		
34		7/7	Su		Sailing		
35		7/8	Mo		Sailing		
36		7/9	Tu		Sailing		
37		7/10	We		09:00 Arrive at Funabashi (Japan)		
38		7/11	Th				Stay at Funabashi Base

1 - 7 Survey Apparatus and Equipments

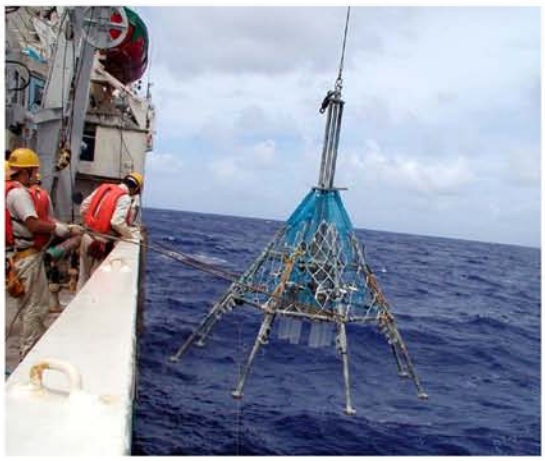
Major apparatus and equipments used in the survey are shown in Table 1- 7-1, and the photographs of main survey equipments are shown in Figure.1-7-1.

Table 1-7-1 Survey Apparatus and Equipments

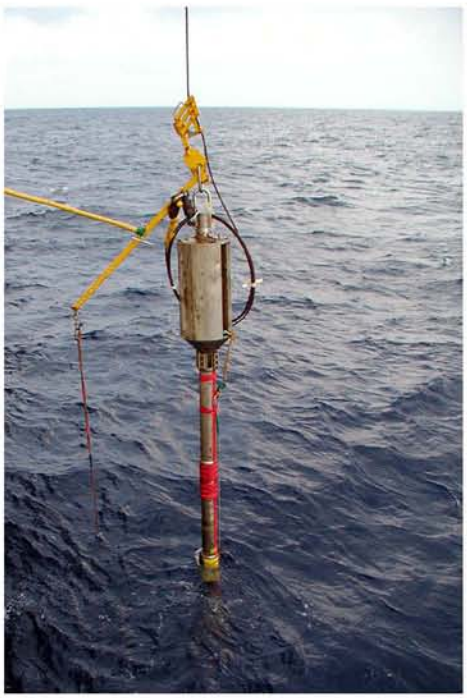
Category	Survey Method		Survey Apparatus and System	Abbreviation	Remarks
Positioning	Satellite Navigation		Global Positioning System GPS+GLONASS	GPS	
Sea Bottom Topography and Geological Survey	Acoustic Survey	Acoustic Sounding Bathymetry	Multi-narrow Beam Echo Sounder Narrow Beam Echo Sounder	MBES NBS	
		Subsurface Geological Structure	Narrow Beam Sub-Bottom Profiler	nSBP	
	Seawater Survey		Conductivity, Temperature and Pressure Measuring System	CTD	
	Sampling		Multi Corer	MC	
			Large Gravity Corer	LC	
			Benthic Multicoring System	BMS	Drilling Machine
Sea Floor Observation	Photograph		Deep Sea Camera		with LC or MC
Data Recording and Processing	On-line Functions Date Storage Functions Off-Line Functions ↓ Track Line Maps etc., Data Analysis		Data Processing System Sensor CPU File Server CPU Host CPU ＥＷＳＣＰＵ ＬＡＮ，ＰＣ，ＩＣＭ	DPS	

Benthic Multicoring System (BMS)

Float of Wire for BMS Operation



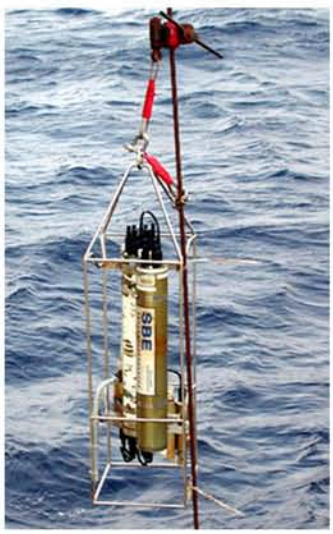
Multi Corer (MC)



Large Corer (LC)

Camera for LC and MC

Pinger



Conductivity, Temperature, Depth Measurement (CTD)

Figure 1-7-1 Photographs of Main Survey Equipments

Chapter 2　Survey Methods

In 2002, the third year of the Stage 2, Phase 1 SOPAC Program, deepsea mineral resources exploration within the Exclusive Economic Zone (EEZ) of the Republic of the Marshall Islands, was carried out. The target mineral is cobalt-rich manganese crust deposit (henceforth cobalt crust).

The cobalt crust deposit within EEZ of the Republic of the Marshall Islands had been surveyed in fiscal years of 1996 and 1998 at thirteen seamounts (JICA/MMAJ, 1997, 1999, Figure 2-1). By the survey, seafloor topographic maps and acoustic reflectivity data by Multi-Narrow Beam Echo Sounder (MBES) of thirteen seamounts had been obtained, and sampling mainly by dredging had been carried out.

On the basis of the information, the survey of this year was aimed to grasp the thickness and grade of cobalt crust at the area where the seabed surface was flat and the cobalt crust assumed to be thick and the survey was carried out obtaining columnar samples using the deepsea drilling system (BMS). The environmental survey was conducted to assess the environmental property of the seamounts of concern..

2 – 1　Selection of Seamounts

The selection of seamounts was made on the basis of the previous survey results (Table 2-1-1, Figure 2-1-1). Seamounts are grouped into two, comparatively shallow-depth seamount of the depth of water at the top of the summit is about 1,500m, and comparatively deep seamount of the depth at the top of the summit is about 2,000m. The comparatively shallow-depth seamounts show good symmetric shape as of typical table mount (guyot) and many of the latter seamounts show intricate topography at the summit.

For the selection of the target seamounts, such factors as, wide extension of flat area, development of flat areas at different depths, typical seamount in the Republic of the Marshall Islands, and so on, were taken in consideration and three seamounts MS01, MS11, and MS12, were selected.

2 – 2　Survey Methods

The major content of the survey is the core sampling by drilling at the above stated three seamounts.

The drilling survey was aimed primarily at the surface of expected exposure of cobalt crust and with gentle slope, considering preferable exploitation condition in the future. The drilling operation was conducted at two sites per day, and to understand the

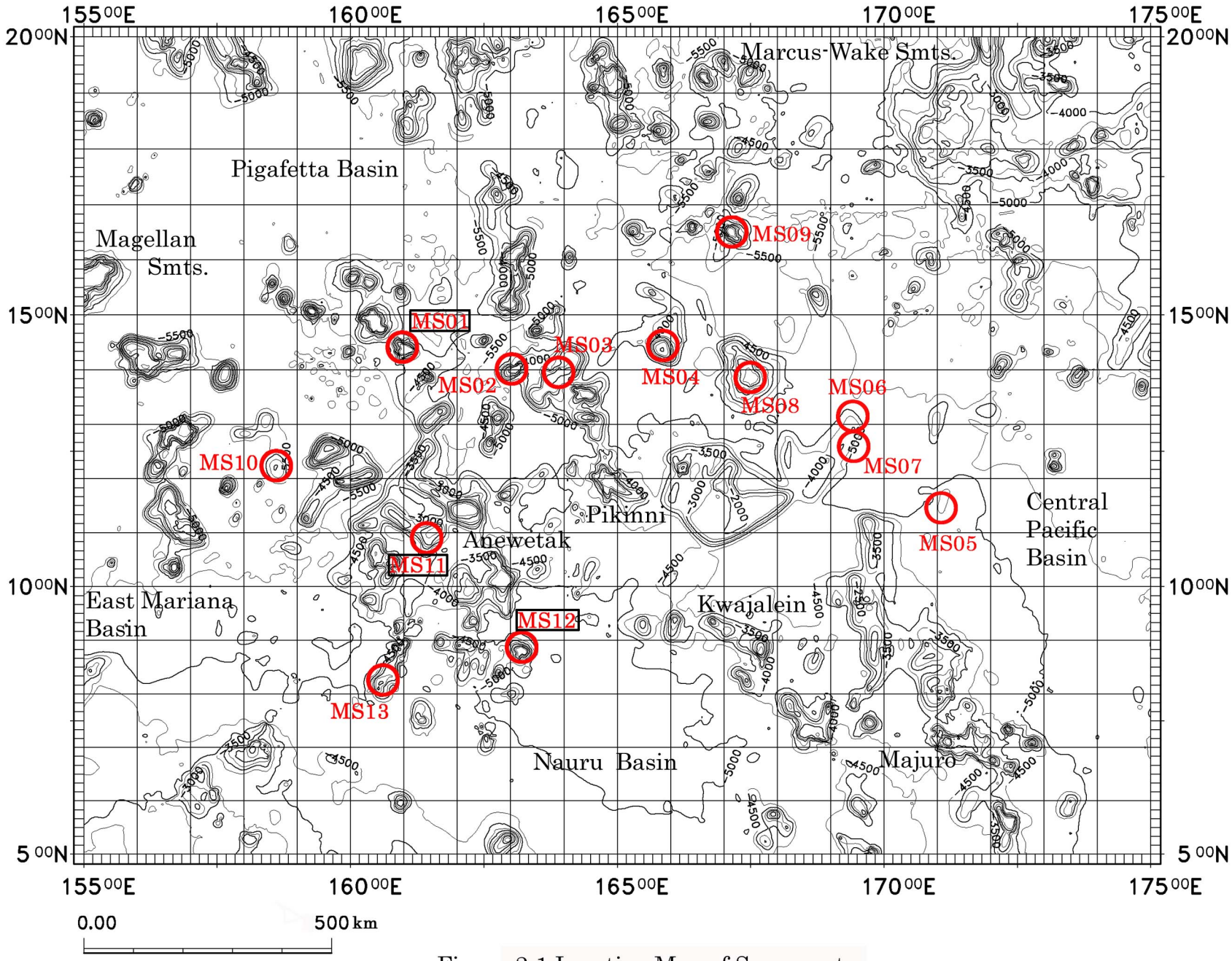


Figure 2-1 Location Map of Seamounts

Table 2-1-1 Outlines of the Surveyed Seamounts

Seamount	Year of Survey	Considered Water Depth (m)	Area of Consideration (km^2)			Co(%)	Average of Average Thickness of each site (mm)	Average of Maximum Thickness of each site (mm)	Number of Sampling Sites	Remarks
			Total Area	Area Covered by Sediments	Exposed Area					
MS01	1996	summit～2,600	738	268	470	0.61	38	70	8	Exposed area is slightly small but shallow. Few flat plains in different depths. Middle size seamount.
MS11	1998	summit～3,000	1,238	582	656	0.68	31	65	7	Exposed area occurs at edge of summit to steep slop. Topography of summit is complicated.
MS12	1998	summit～2,000	462	228	234	0.68	23	63	12	Exposed area is relatively small but it occurs at shallow depth.

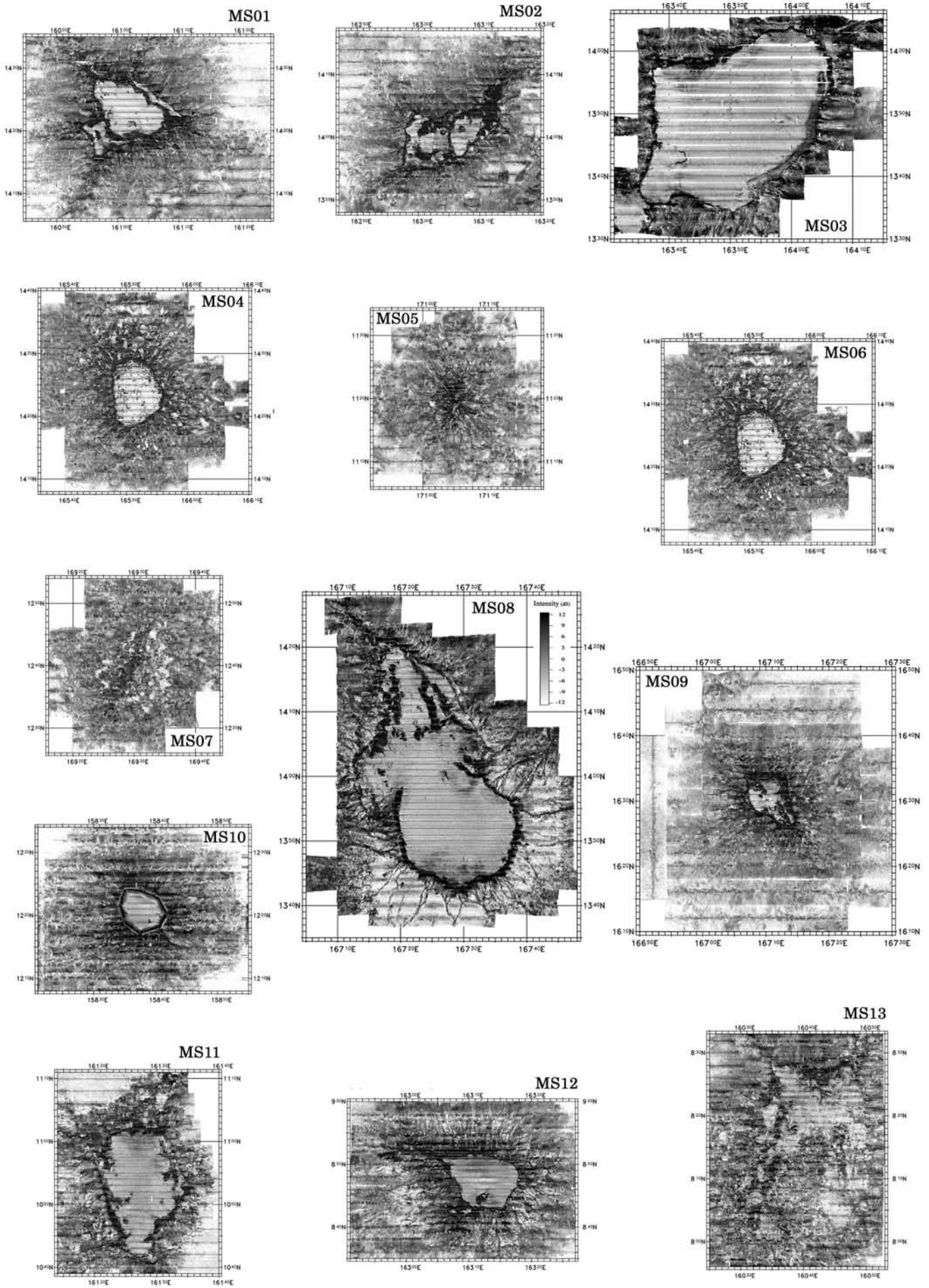


Figure 2-1-1 Acoustic Reflection Intensity Maps of Seamounts of the Marshall Islands

variation of thickness of each site, generally, three holes (points) at each site were drilled taking horizontal distance of approximately 50m. Drilling depth of less than 1m was considered to be enough to confirm the thickness of cobalt crust and bedrock at each hole. In addition to this, at least one drill hole of drilling depth more than 1.5m was drilled at each seamount to confirm the characteristics of underlying bedrock. When the drilling had to be canceled due to bad weather, sampling by large gravity corer (LC) was conducted to obtain the information of sediments and underlying cobalt crust.

The selection of the drilling site was made based on topographic map and acoustic reflection intensity map considering the following survey objectives.

a. Mapping of cobalt crust of the summit area of seamount
b. Distribution of cobalt crust with depths
c. Horizontal continuity of cobalt crust distribution
d. Development of cobalt crust beneath overlying sediments

At the three seamounts, MS01, MS11, and MS12, during nighttime, supplementary topographic survey was done adding subordinate track lines on the previous survey for the purpose of obtaining more detailed topographic map. On the three seamounts, sediments samples were collected by MC (Multi Corer) for the environment survey.

2 – 3 Numbering

The numbering system used is as follows.

For sampling points: Year – S – Name of Seamount – Sampling Method – Sampling No.

"S" denotes SOPAC. The name of the seamount is derived after the naming by the previous survey. Sampling number of LC is the continuation of the sequential numbers of AD, CB, and LC used in the previous survey. It is the first time to conduct drilling (BMS) and MC for these three seamounts, thus the sample number begins from 01 at each seamount.

Example:	02SMS01BMS01	(BMS Site Number)
	02SMS01LC15	(LC)
	02SMS01MC01	(MC)

For each drilling point (hole), A, B, C was added to the site number.

2 – 4 Positioning of Vessel

The Position of the vessel was determined by the global positioning system (GPS). During the drilling by BMS, position control of the vessel was made by the dynamic positioning system (DPS) maintaining the position of the cable connecting BMS to form reasonable catenary line around the landing point of BMS.

Position of the drilling point of the BMS is determined at the time of landing of BMS by the GPS set at the stern of the ship, and water depth of that point is determined by the acoustic sounding. The positioning of BMS on navigation is calculated by means of Pythagoras's theorem using the positioning data of GPS, length of the cable, and water depth given by the acoustic sounding, assuming that BMS is located directly behind the ship, and from this wake map of BMS was made.

The position of the sampling point of LC and MC was determined by the record of GPS set near the crane at the starboard and water depth was obtained by acoustic sounding.

The coordinates used for the measurement was WGS 84, and the time of the ship clock was local time of 165° E (GMT +11 hours).

2 – 5 Acoustic Survey

The acoustic survey had been conducted in the previous year and the supplementary survey was carried out this year to improve the map accuracy. The vessel was navigated along the subordinate tracking lines with the cruise speed of 10 knots to 12 knots per hour and MBES sounding was made at every 8 to 12 seconds of time interval, and for Narrow Beam Sounder (NBS) at every 8 seconds. On MBES survey, acoustic reflection intensity of the seabed is obtained along with the sounding survey, so that the sea bottom profiling survey by narrow beam Sub-Bottom Profiler (nSBP) was done simultaneously with topographic survey.

2 – 6 Sampling

In order to understand the occurrence of cobalt crust, the sampling by BMS and LC was conducted. The drilling by BMS was given the first priority. In case the drilling operation was hampered due to bad weather, the sampling by LC was done instead to understand the distribution of sediments and the occurrence of cobalt crust beneath the sediments. In the environment survey, samples were obtained by MC.

2 – 7 Processing and Analysis of Survey Data

On vessel, processing and analysis of the obtained data were done using the data analysis system, the MBES off-line processing system, and personal computers (PC). The flow sheet of data processing and analysis is shown in Figure 2-7-1. Data were processed and analyzed on the vessel as a rule. Integrated analysis and part of processing and analysis of data were done after the cruise.

2 – 8 Laboratory Sample Test

Samples of cobalt crust and rocks were tested in laboratory.

Chemical analysis was done for cobalt crust. Rock samples were studied by thin section observation, petrochemical analysis, and age determination. For calcareous rocks and unconsolidated sediments, the fossil test was done.

2 – 9 Criteria of Classification

2 - 9 – 1 Topographic Division of Seamount

Topographic characteristics of seamounts were divided into three, summit, slope and foot of seamount for convenience, and the slope was further subdivided into upper part, middle part, and lower part. The topographic classification is shown in Table 2-9-1-1 and the schematic sketch of topographic subdivision is given in Figure 2-9-1-1.

Table 2-9-1-1 Topographic Classification of Seamount

Classification		Characteristics of Feature
Summit	Central Part	Central part of summit with flat or gentle slope
	Marginal Part, Periphery, Edge	Transition zone from the central part of summit to the upper part of slope
Slope	Upper Part	Steeply inclined upper part of slope
	Middle Part	Area between the upper part and lower part of slope
	Lower Part	Gently inclined lower part of slope
Foot of Seamount		Transitional zone from the lower part of slope to the ocean floor

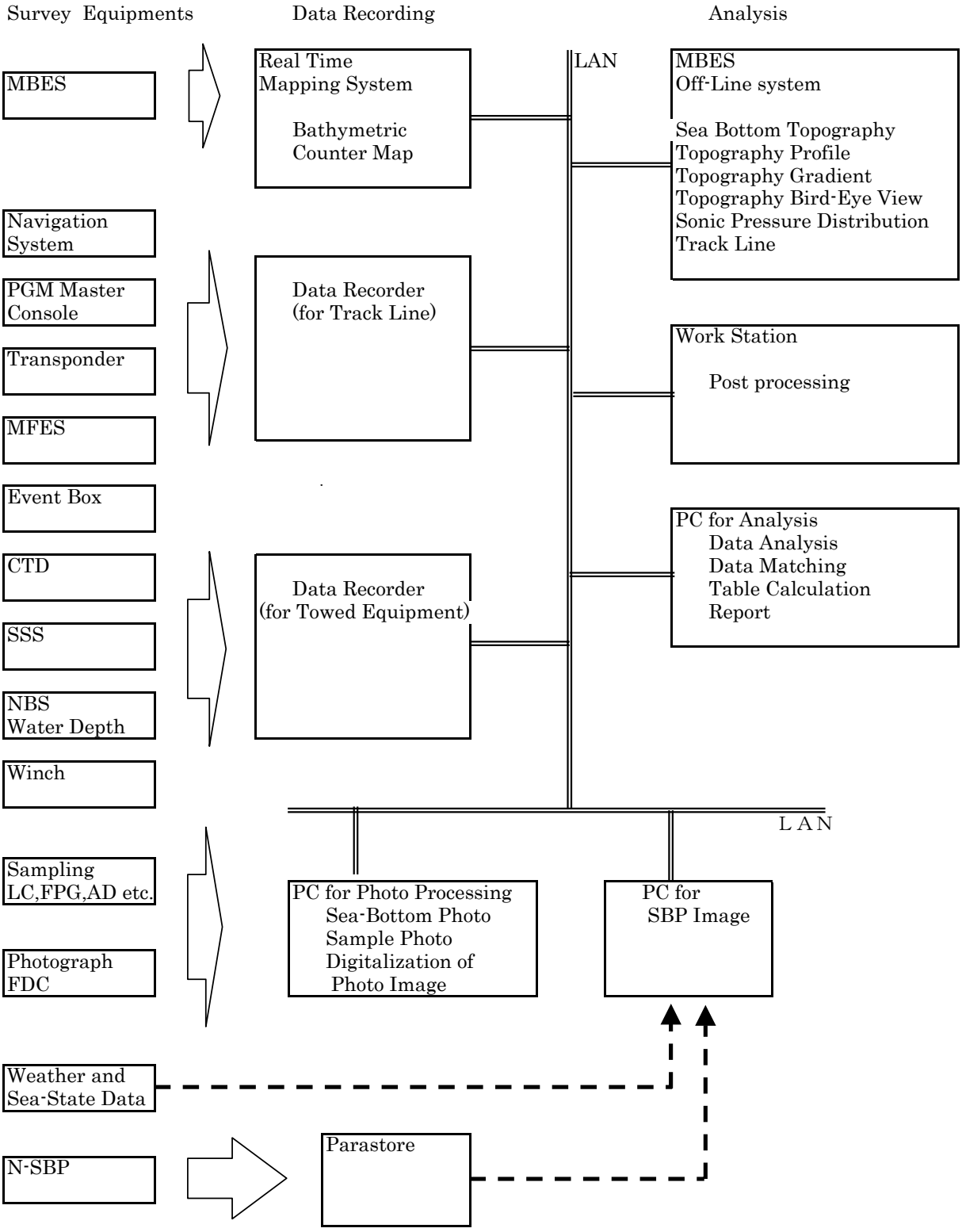


Figure 2-7-1 Data Processing and Analysis Flow Sheet

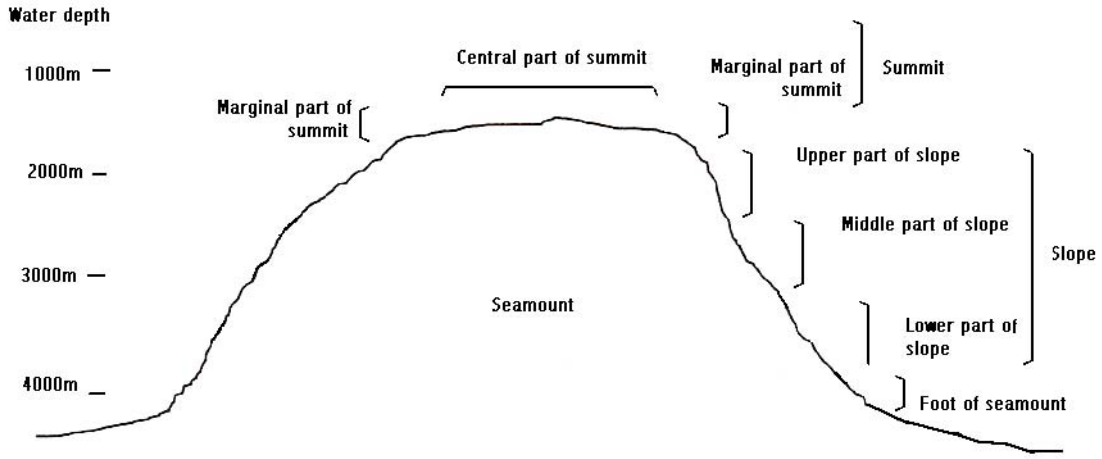


Figure. 2-9-1-1 Schematic Model of Seamount Subdivision

In case of a flat summit seamount, the summit corresponds to the central part of summit. Since the subdivision is made mainly by the extent of the inclination of topography, subdivision in a seamount varies with depths. Seamounts are located at variety of depths, e.g. sometimes on a plateau, water depth of the topographic subdivision varies depending on seamount. For this, the slope area and inclination angle of seamounts were calculated according to the subdivision of each seamounts.

2 - 9 - 2 Classification of Cobalt Crust Type

Cobalt crust is subdivided into three types shown in Table 2-9-2-1. The schematic figure of the distribution of cobalt crust is shown in Figure 2-9-2-1.

Table 2 -9 -2 -1　Classification of Cobalt Crust

Type	Definition
Crust	Manganese oxides covering over the bedrock of a seamount, autochthonous in origin. In case the sample lacks bedrock, it is called crust fragment.
Cobble Crust, (Boulder Crust)	Cobble and boulder size crust with diameter of more 8cm, and whose entire surface is covered by manganese crust.
Nodule	Gravel of which surface is covered by manganese oxides. Diameter is less than 8cm. Normally it takes globular to ellipsoidal shape.

Other than that classification, thin manganese oxides coated over bedrocks or gravels within 1 mm thickness are called coated crust.

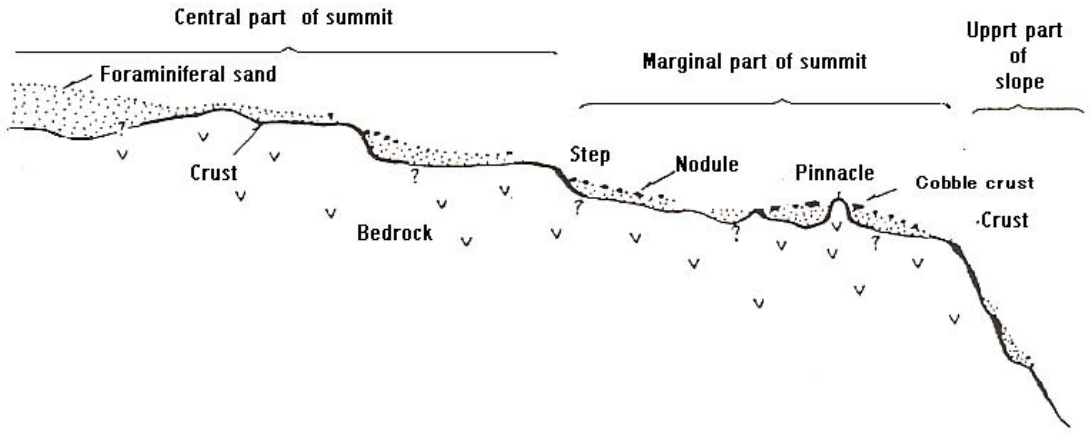


Figure. 2-9-2 -1　Distribution of Cobalt Crust

2 - 9 - 3　Layer Division of Cobalt Crust

In order to understand the historical occurrence of cobalt crust, the following seven divisions of classification were used on the basis of stratified characteristics of samples.

Type 1　Homogeneous, black in color, compact texture

Type 2　Homogeneous, weakly mottled to columnar substructure

Type 3　Mottled to columnar structure, openings are filled with clay

Type 4　Ditto., openings are not filled with clay

Type 5　Compact, fine texture, partly porous, brownish colored with phosphoric clay

Type 6　Porous layer with cokey appearance

Type 7　Thin laminated layer with peeling off characteristics along lamina

Layered cobalt crust is numbered, from the outermost (top or near the top) layer to the inner side (toward deep), layer 1, layer 2, layer 3, layer 4, and so on.

2 - 10　Environmental Survey

2 - 10- 1　Objectives

An environmental survey was conducted as a baseline study to evaluate the magnitude of potential mining impacts on the deep-sea environment. In this survey distributions of benthic organisms were examined; and properties of the sediment, which are the key parameters affecting the habitat conditions of benthic organisms, were studied.

2- 10- 2　Study Subjects

Following items were examined by the environment survey.

Benthic Organisms
- Meiobenthos
- Macrobenthos

Sediment Properties
- Total Organic Carbon
- Total Nitrogen

2 - 10- 3　Methods

2 - 10- 3 - 1　Observations, Sampling and Sample Processing

（1）Benthic Organisms and Sediment Properties

Sediment samples for both the benthic organism study and sediment property

study were collected using a multiple-corer. The cores were sliced at every 1 cm from the surface to a 3 or 5 cm depth, and then were processed as described in the following (until the analysis) (Table 2-10-3-1).

Table 2-10-3-1 Study Subjects, Sample Processing and Preservation

Study Subjects	Sample processing and preservation
Meiobenthos	Sliced into 3 layers at every 1 cm, fixed and stained with neutralized formalin (10% V/V) with Rose Bengal and then kept refrigerated until the analysis
Macrobenthos	Sliced into 5 layers at every 1 cm, fixed and stained with neutralized formalin (10% V/V) with Rose Bengal, and then kept refrigerated until the analysis
Total Organic Carbon and Total Nitrogen	Sliced into 3 layers at every 1 cm, and kept frozen until the analysis

2 - 10 - 3 - 2　Analysis

（1）Benthic Organisms

1）Meiobenthos

Materials were stained with Rose Bengal, and then sieved at 32 μm and 300 μm mesh sizes. Organisms, which passed through the 300 μm mesh and remained after sieving at 32 μm, were identified and individuals were counted. Foraminifera were excluded from the quantitative analysis, as they are fragile and difficult to count.

2）Macrobenthos

Materials were stained with Rose Bengal, and then sieved at a mesh size of 300 μm. Organisms that remained on the mesh were identified and individuals were counted. As with the meiobenthos samples, faunal groups, that were difficult to count, were excluded from the quantitative analysis.

（2）Sediment Properties (Total Organic Carbon and Total Nitrogen)

After samples were dried, the total carbon (organic carban + inorganic carban) and total nitrogen were measured using a CHN analyzer (Yamagimoto MT-5). Inorganic carbons were removed from the dried samples with 4N hydrochloric acid, and the treated samples were re-dried and weighed as organic carbon. The inorganic carbon that was obtained from this process was considered as the difference between total carbon and organic carbon.

Chapter 3　Results of the Survey

3 - 1　Outline of the Sea Area

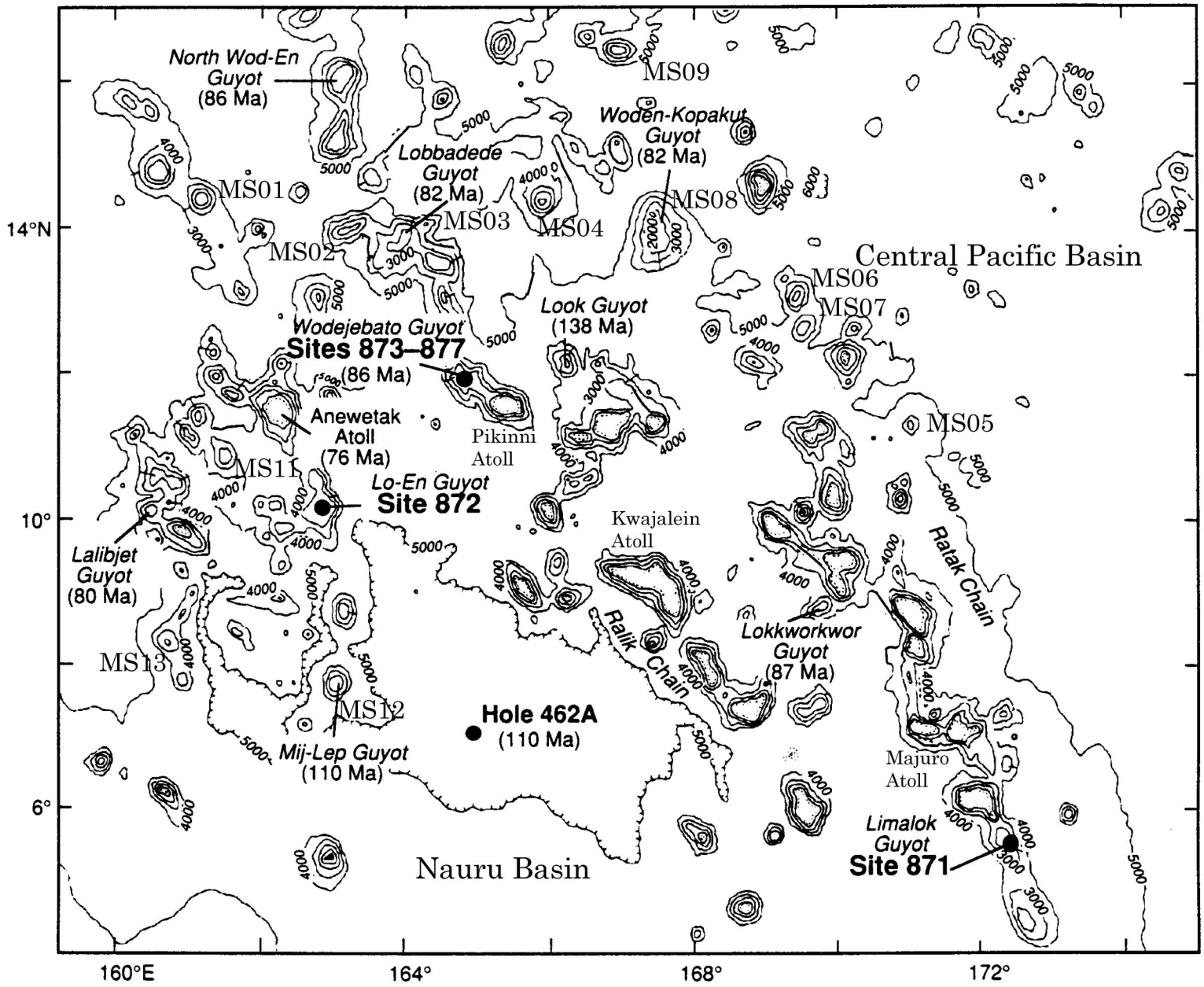
3 - 1 - 1　Topography

The Marshall Islands is located in the northwestern part of the Central Pacific, and surrounded the east by the Central Pacific Basin and the west and southwest by the East Mariana Basin and the Nauru Basin, and is aligned in the NNW-SSE direction （Figure 3-1-1-1）. The southern extension of the islands is linked to the Gilbert Islands and the Cook Islands, and in the northern extension is linked to the Marcus-Wake Seamount Chain and the Magellan Seamount Chain.

The Central Pacific Basin extending east of the Marshall Islands forms a flat, ocean floor topography in general except local swells and troughs, and constitutes the ocean floor with water depth of 5,000m to 6,000m. The Nauru Basin and the East Mariana Basin extending western part of the Marshall Islands have ocean floor of the water depth of over 5,500m, and the western margin of the East Mariana Basin reaches up to the Mariana Trench. Water depths to the base of seamounts or atolls in the sea area of the Marshall Islands are 5,000m to 6,000m, and relative height of seamounts are 3,500m to 4,000m, however, some of seamounts exceed relative height over 5,000m.

Topographically, atolls and seamounts in the Marshall Islands align in NNW-SSE direction forming three rows of chains. They are; from east to west, the Ratak Chain including the Majuro Atoll, the Ralik Chain including the Kwajalein Atoll and the Pikinni Atoll, and a group of seamounts, distributed in the northwest and southeast direction, including in Anewetak Atoll. As the characteristics of the group of seamounts, it is reported that they do not show time sequential arrangement as the Hawaii-Tenno Seamount Chain (Davis et al., 1989), and the distribution of atolls is comparatively abundant in the south, and seamounts and atolls show a pared distribution. Moreover, many of these seamounts are flat summit seamounts with dome shape, and water depths of summit are 1,000m to 1,500m.

The MS01 seamount belongs to the Ralik Chain, and the MS11 and the MS12 seamounts belong to the group of seamount including the Anewetak Atoll. The MS12 seamount is called Mij-Lep Guyot



Modified from Pearson(1995)

● Site 871 ODP site
(110 Ma)（Radiometric Age）

Figure 3-1-1-1 Bathymetric Map of the Marshall Islands

3 - 1 - 2 Geology

The age of oceanic floor reported by magnetic stripes constituting the oceanic crust of the Central Pacific Basin surrounding the Marshall Islands is Jurassic Era, thus the seamounts and atolls of the Marshall Islands are built on the basement of the oceanic crust of Jurassic Era (Larson, 1976, Cande et al., 1978).

Among the seamounts of the Marshall Islands, drilling surveys were conducted at the flat summit seamounts such as Limalok, Lo-En, Wodejebato under the Ocean Drilling Program (ODP), and geologic situation has been clarified (Haggerty and Premoli-Silva, 1995, and others). These seamounts are constituted of basalt and pyroclastics as the basal part of the seamounts, neritic calcareous sediments overlying the basalt while the seamounts had been laid under the shallow sea environment after the quiescence of volcanic activity. Pelagic sediments at the top deposited after the seamounts had submerged into the deep sea (Bergersen, 1995a).

Basaltic rocks, forming the basal part of the seamounts and atolls of the Marshall Islands, are alkali basalt and its differentiated hawaiite or trachite (Davis et al., 1989, Malcolm et al., 1989, Christie et al., 1995). Moreover, it is known that the chemical characteristics of rare elements and isotopic composition of these basaltic rocks resemble with those from volcanic islands of the French Polynesian Region. Seamounts and atolls of the Marshall Islands are thought to be formed associated with volcanic activity of the French Polynesian Region (Staudigel et al., 1991, Anthony et al., 1995). The formation of seamount and atoll of the Marshall Islands is separated into two stages, Middle Cretaceous (Aptian to Cenomanian) and Late Cretaceous (Coniacian to Campanian), according to the age determination by the Ar-Ar dating of basaltic rock and the fossil fauna of the neritic limestone of seamount and atoll (Lincoln et al., 1993, Haggerty and Premoli-Silva, 1995). These seamounts are not likely to be formed from a single hot spot like the Hawaii Seamount Chain, but are derived from several hot spots develop in the French Polynesian Region, and relocated to the present position (Lincoln et al., 1993, Bergersen, 1995b).

According to the result of ODP, it is known that the situation and the time of the formation of neritic limestone which overlying basaltic rocks, depend upon the submerging history of each seamounts, and differ from one to the other (Haggerty and Premoli-Silva, 1995). At the Lo-En Seamount (Site 872) south of the Anewetak Atoll, the neritic limestone is not observed there, and pelagic sediments directly overlie basaltic rocks. At the Limalok Seamount (Site 871) and Wodejebato Seamount (Site 873-877), the thickness of neritic limestone is, 289m and 82m to 183m, and from biostratigraphic correlation, they are assumed to be from late Paleocene (57Ma) to middle of Eocene (47

Ma) at the Limatok Seamount, and Albian (107Ma) of Middle Cretaceous to Maestrihician (65Ma) of Late Cretaceous at the Wodejebato Seamount. It is suggested that the above two seamounts were under the neritic environment during above periods. From foraminiferal fossil or nanno plankton fossil fauna derived from the pelagic ooze which overlies the top of the seamount, the age of the pelagic sediments is assumed to be Pliocene to recent at the Limaloc Seamount and the Lo-En Seamount, and Miocene to recent at the Wodejebato Seamount (Person, 1995). Fossil record from the pelagic sediments is not successive with time, and frequent interruption exists, suggesting the existence of hiatuses.

On the cobalt crust in the EEZ of the Marshall Islands, there are reports by Hein et al. (1988) or Hein et al. (1990). They reported that there develop thick cobalt-rich crust with the maximum thickness of up to 100mm, and they are rich in Co and Pt. The time of the precipitation of manganese oxides associated with the formation of cobalt crust is after the quiescence of the deposition of neritic limestone by the submergence of seamounts, and thought mainly to be during Eocene and Oligocene (Watkins et al., 1995).

3 - 2 MS01 Seamount

In the survey of fiscal year 1996, acoustic survey including the Multi-narrow Beam Echo Sounder (MBES) and sampling by dredging and large gravity Corer (LC) were conducted at the MS01 Seamount. In this year, the supplementary acoustic survey by the MBES taking subordinate track lines between the previous lines, and drilling by BMS and sampling by LC were conducted.

3 - 2 - 1 Topography and Circumstances of Seafloor

The acoustic survey of seamount itself had been conducted in 1996, and thus newly obtained information by the acoustic survey of this year are limited. The bathymetric map and the acoustic reflection intensity map by MBES are shown in Figures 3-2-1-1 and 3-2-1-2.

3 - 2 - 1 - 1 Topography

The MS01 seamount is a plateau seamount of horizontal extension of about 70km in E-W direction and about 60km in N-S direction with the center at 14° 23' N, 151° 02' E. The shallowest depth is 1,040m and relative altitude is about 4,000m.

The shape of the summit area shows triangular shape with long axis of WNW-ESE direction and the area of the slope is 443km^2. Average slope angle of the summit area is 4.9 degrees, and the summit area is constituted of two terraces bordered by the slope of annular zone with depth of 1,300m to 1,400m surrounding the summit. The upper terrace forms the central part of the summit with the water depth of 1,300m. The lower terrace is the flat area with the water depth of 1,400m or more, and it extends widely to southwestern part of the summit area. Several depressed grounds with an extent smaller than 1.5km by 1.5km are observed at the south and northwestern part of the summit.

The upper slope area has steep slope, with average slope angle of 26 degrees, and average angle of middle and lower slope area are 22 degrees and 10 degrees, respectively. The seamount has characteristic topographic feature with five radial ridges.

3 - 2 - 1 - 2 Circumstances of Seafloor

At the shoulder of the marginal part of the summit, there develops dark tone area, and the acoustic reflection intensity distribution shows the highest intensity. At the same time, along the annular zone with water depth of 1,300m to 1,400m dividing two terraces, there occurs an area of dark image tone suggesting the development of exposed

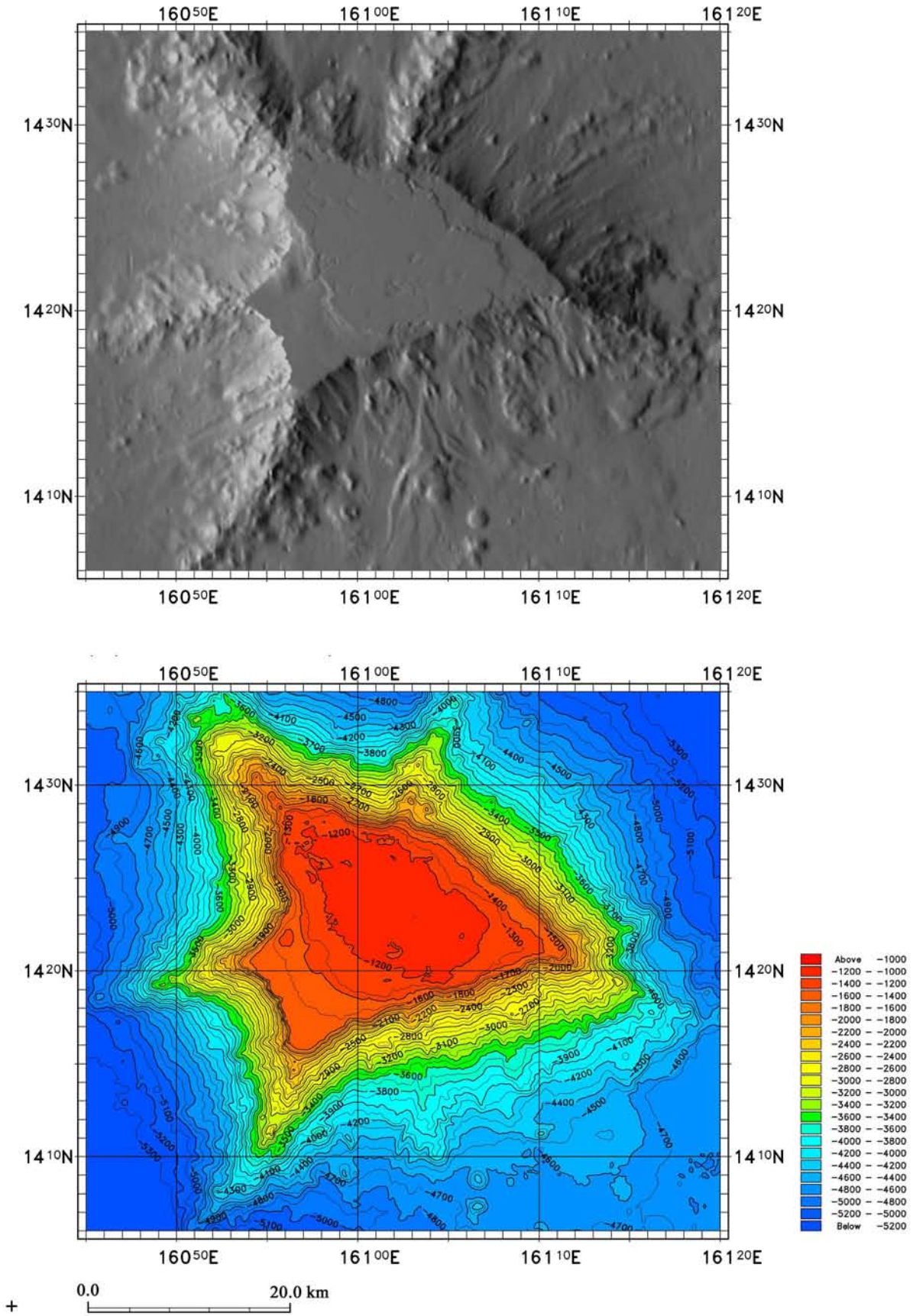


Figure 3-2-1-1 Bathymetric Map and Shaded Map of MS01 Seamount

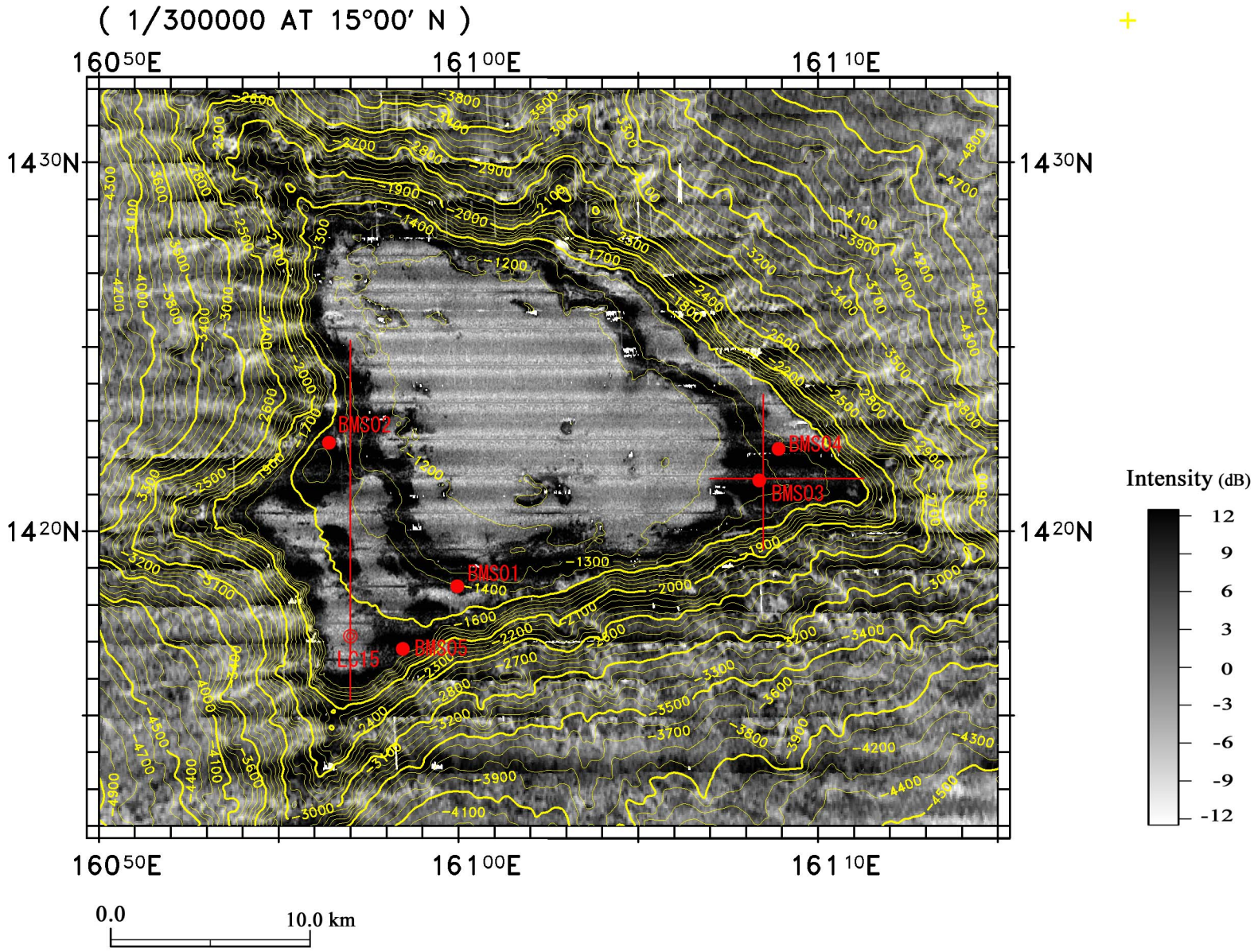


Figure 3-2-1-2 Acoustic Reflection Intensity Distribution of MS01 Seamount

rocks. At the northeastern part of the summit, zonal dark tone area occurs corresponding to slope with angle of more than 5 degrees and it also suggests an exposure of bedrock. At the depressed grounds in the south and northwest of the summit, there occurs dark tone area. Most of the summit area shows light tone in the acoustic image showing low acoustic reflection intensity distribution suggesting the area to be composed of surpassing unconsolidated sediments.

On the slope, dark tone areas occur from margin of the summit to the upper part of the slope, and along the five radial ridges, showing these areas are composed of exposed rock. Along the slope area bounded by ridges, the area of light tone showing the low acoustic reflection intensity extends widely as slope angle becomes gentler, suggesting wider extension of unconsolidated sediments in these areas.

According to the SBP survey conducted in 1996, the thickness of unconsolidated sediments of the upper terrace of the summit is assumed to be 10m to 85m, and that of the lower terrace at the northeast and southwest of the summit is 10 m to 20m.

3 – 2 – 2 Results of Sampling

In the survey of 1996 at the MS01 seamount, samples were collected at seven points by the arm dredge (AD) and at seven points by the large gravity corer (LC), and deepsea camera (FDC) observation was conducted along one track line (Table 3-2-2-1). As the results, average thickness of 33mm and average grade of Co0.67% were obtained for the cobalt crust of MS01 seamount.

This year, drilling of 16 holes at five drilling sites, MS01BMS01 to MS01BMS05, and LC sampling at one site were conducted.

Location of sampling site, location of drilling point, correlation photographs of drill cores, the result of sampling are shown in Figures 3-2-2-1, 3-2-2-2, 3-2-2-3 and Table 3-2-2-2. Additional data, such as photograph of the seafloor of drilling point, photographs of drill cores, columnar profile of drill cores, photographs of seafloor of LC and MC sites, columnar profile of LC and MC samples are given in Appendixes 1 to 5.

In order to grasp the relation between the acoustic reflection intensity distribution of the MBES (hereafter acoustic image) and exposure of rocks, a detailed acoustic survey at the east and west of the summit area of the MS01 seamount, cruising the vessel with 6 knot per hour at the boundary area corresponds to the boundary of dark and light tone in the acoustic image, was conducted. Obtained acoustic maps are shown with seafloor photographs of sampling points in Figure 3-2-2-4 (SBP01 line and SBP02 line) and Figure 3-2-2-5 (SBP03 line).

The results of sampling at each site are given below.

Table 3-2-2-1 Sampling Results of Previous Year in MS01 Seamount

No.	Sampling No.	Bottom Touch			Bottom Release			Topographic Division	Length /Amount (cm)/(kg)	Rock	Mn Crust
		Latitude	Longitude	Depth (m)	Latitude	Longitude	Depth (m)				
1	96SMS01LC	14°23.927′ N	160°50.115′ E	4,267				W.lower slop	230cm	foraminifera sand	
2	96SMS01LC	14°27.891′ N	160°56.625′ E	1,195				NE.summit edge	95cm	foraminifera sand	
3	96SMS01LC	14°21.990′ N	160°57.401′ E	1,226				W.summit edge	8cm		crust
4	96SMS01LC	14°18.904′ N	161°01.419′ E	1,218				S.summit edge	8cm		crust
5	96SMS01LC	14°21.992′ N	161°09.093′ E	1,317				E.summit edge	3cm		crust
6	96SMS01LC	14°26.002′ N	161°04.378′ E	1,234				NE.summit edge	0cm	-	-
7	96SMS01AD	14°16.823′ N	161°00.337′ E	2,218	14°17.129′ N	161°00.823′ E	2,014	S.middle slop	4.80kg	basalt, conglomerate	crust
8	96SMS01AD	14°17.888′ N	161°02.076′ E	1,815	14°18.161′ N	161°02.592′ E	1,625	S.upper slop	4.49kg	basalt, limestone	crust
9	96SMS01AD	14°15.432′ N	161°03.843′ E	3,284	14°15.861′ N	161°04.471′ E	3,227	S.lower slop	35.40kg	conglomerate, mudston	cobbly crust, nodule
10	96SMS01AD	14°17.023′ N	161°05.923′ E	2,825	14°17.394′ N	161°06.472′ E	2,762	S.lower slop	32.80kg	lapilli tuff, conglomerat	crust, nodule
11	96SMS01AD	14°26.010′ N	161°04.368′ E	1,242	14°25.621′ N	161°04.830′ E	1,269	NE.summit edge	25.50kg	basalt	crust, nodule
12	96SMS01AD	14°18.980′ N	161°04.831′ E	1,408	14°19.214′ N	161°05.368′ E	1,265	S.summit edge	220.26kg	conglomerate	cobbly crust
13	96SMS01AD	14°21.217′ N	160°53.234′ E	2,398	14°21.193′ N	160°53.685′ E	2,089	W.middle slop	1.59kg	basalt	crust
14	96SMS01LC	14°28.299′ N	160°56.410′ E	1,231				NW.summit edg	4cm		crust

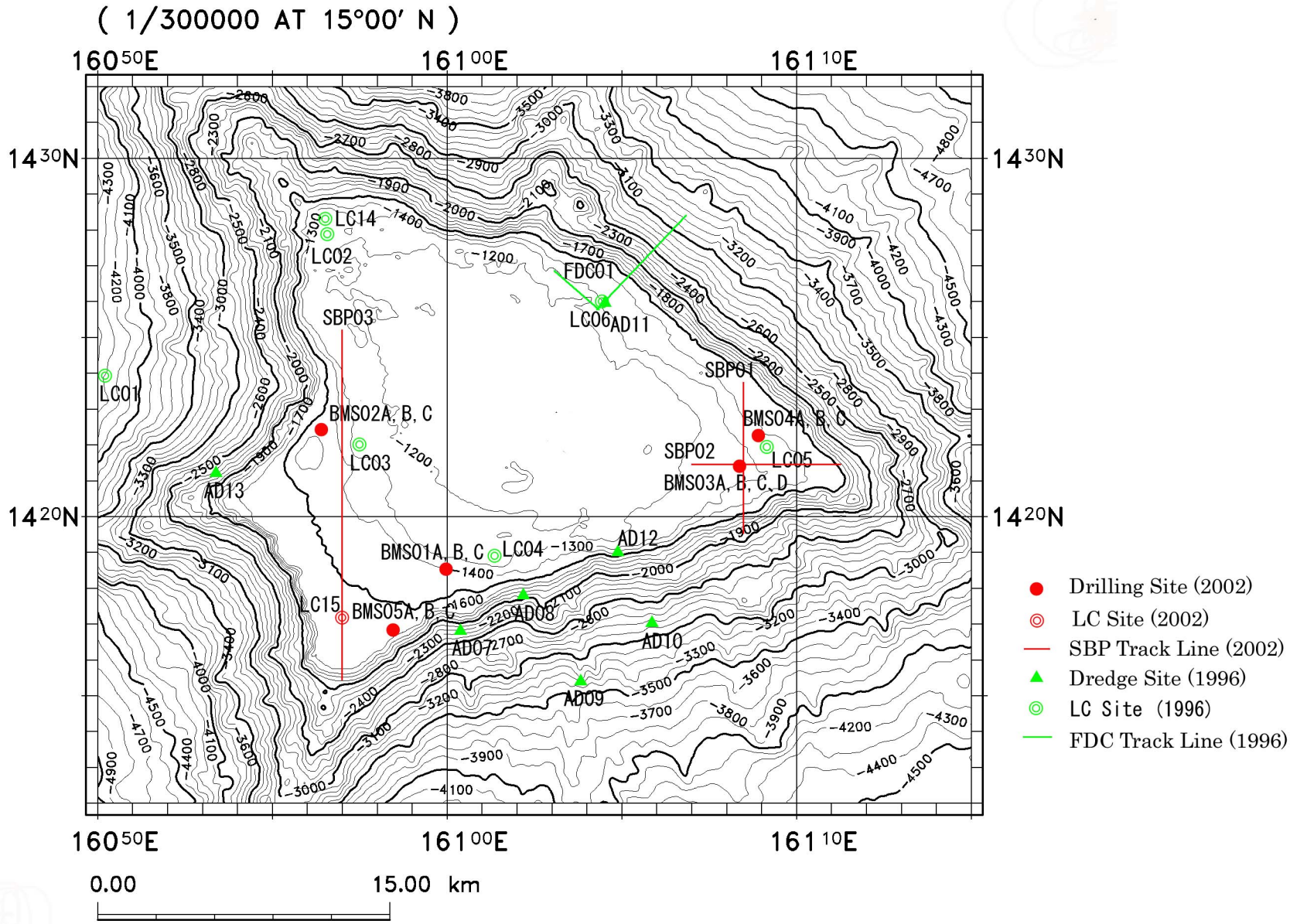


Figure 3-2-2-1 Sampling Location of MS01 Seamount

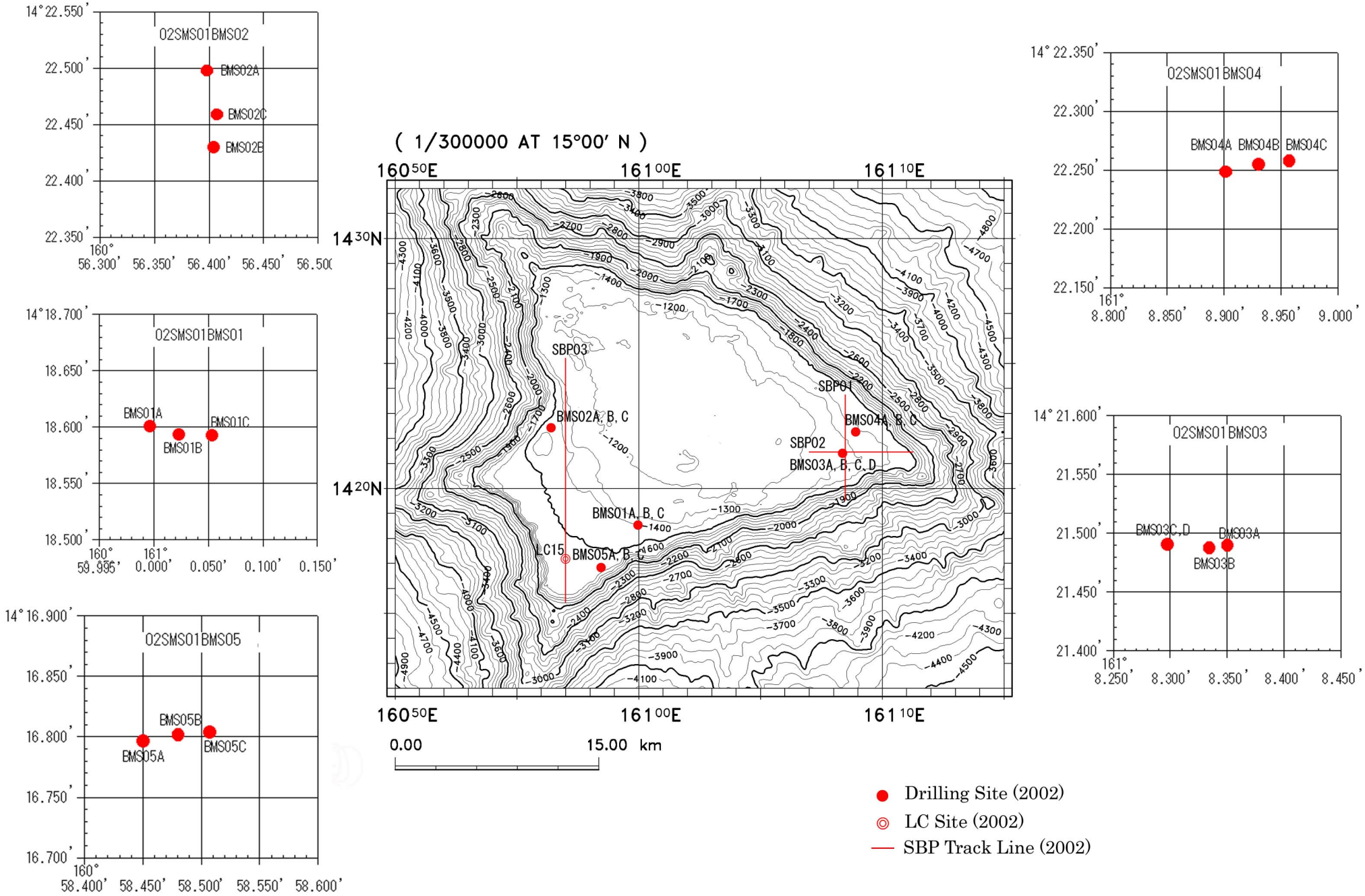


Figure 3-2-2-2 Location of Drilling Point in MS01 Seamount

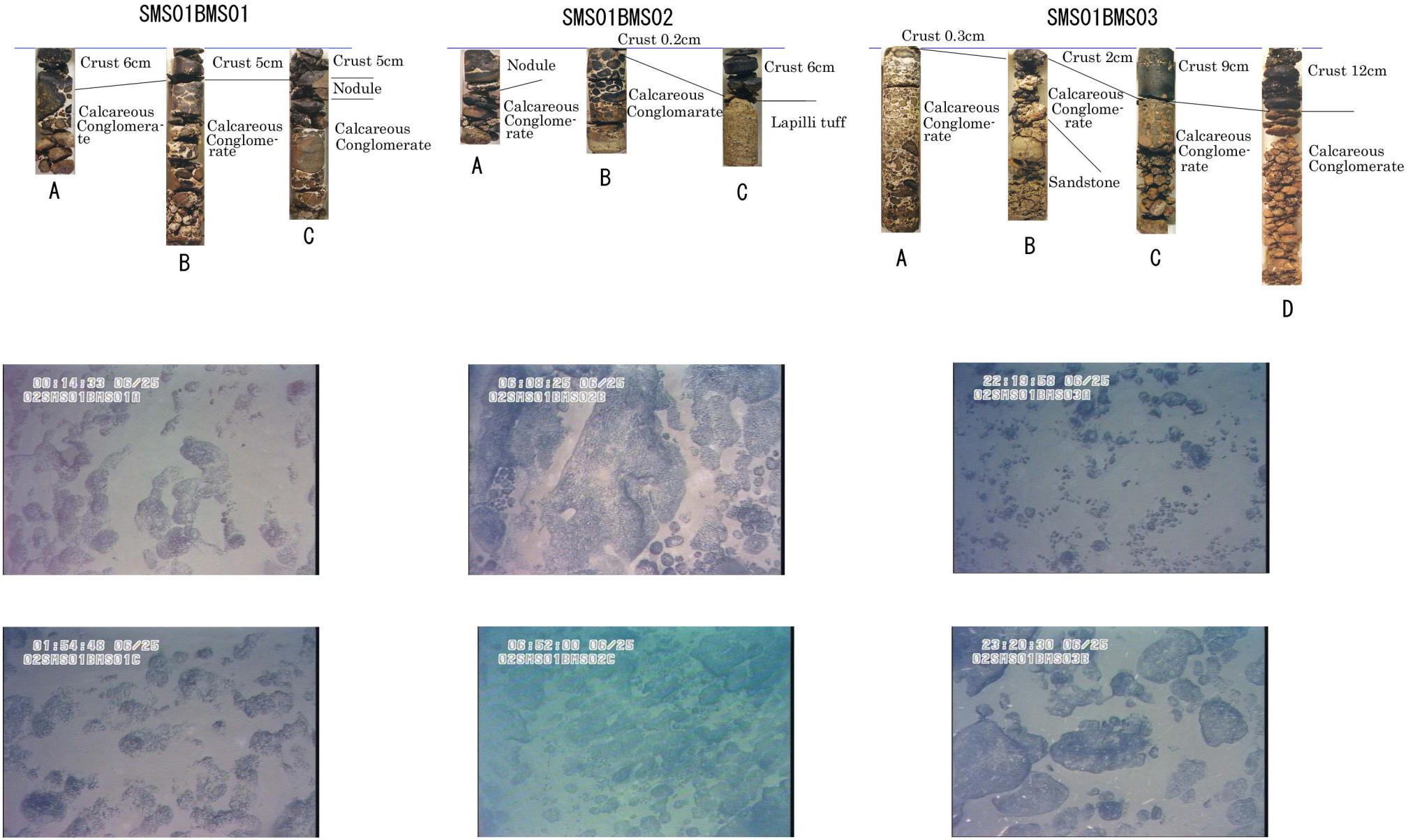


Figure 3-2-2-3 Correlation Core Photographs of MS01 Seamount (1)

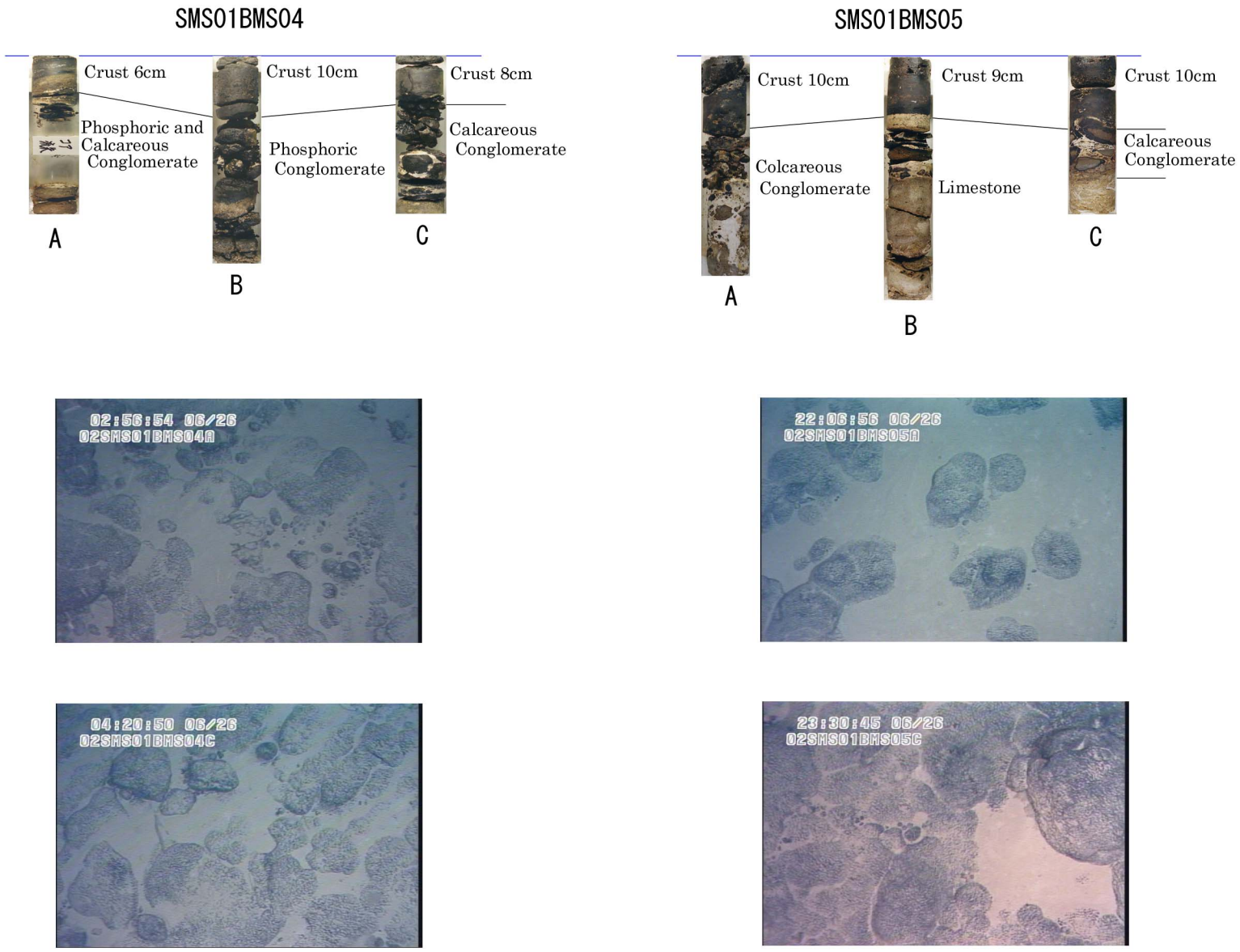


Figure 3-2-2-3 Correlation Core Photographs of MS01 Seamount (2)

Table 3-2-2-2 Sampling Results of MS01 Seamount

No.	Drill Site	Drill Point	Locations		Water Depth (m)	Core Bar-rel	Operation(cm)		Drilling Length (m)	Core Length (m)	Core Recovery (%)	Sediments (cm)	Rock Type (cm)
			Latitude	Longitude			start	end					
1	BMS01	02SMS01BMS01A	14°18.600′ N	160°59.997′ E	1,388	1	0	37	37	24	73	4	crust(6),cal.conglo.（18）
2		02SMS01BMS01B	14°18.593′ N	161°00.024′ E	1,385	1	0	40	40	35	88	0	crust（5）,cal. conglo.（30）
3		02SMS01BMS01C	14°18.592′ N	161°00.054′ E	1,382	1	0	34	34	32	94	0	crust（5）,nodule（4）,Cal. conglo.（23）
4	BMS02	02SMS01BMS02A	14°22.497′ N	160°56.400′ E	1,461	1	0	49	49	19	42	4	ﾉｼﾞｭｰﾙ(4),cal. conglo.（15）
5		02SMS01BMS02B	14°22.458′ N	160°56.409′ E	1,457	1	0	35	35	20	74	8	cal. conglo.(16),sandstone(4)
6		02SMS01BMS02C	14°22.429′ N	160°56.405′ E	1,457	1	0	34	34	21	70	4	crust(6),lapilli tuff(15)
7	BMS03	02SMS01BMS03A	14°21.489′ N	161°08.351′ E	1,286	1	0	49	49	34	100	15	cal. conglo.（34）
8		02SMS01BMS03B	14°21.487′ N	161°08.335′ E	1,287	1	0	36	36	33	92	0	crust（2）,cal. conglo.(11),sandstone（20）
9		02SMS01BMS03C	14°21.490′ N	161°08.298′ E	1,287	1	0	40	40	34	87	1	crust（10）,cal. conglo.(24)
10		02SMS01BMS03D	14°21.490′ N	161°08.298′ E	1,287	1	0	162	162	45	28	0	crust（13）,cal. conglo.（32）
11	BMS04	02SMS01BMS04A	14°22.248′ N	161°08.902′ E	1,376	1	0	71	71	25	37	4	crust(6),phos.conglo.（19）
12		02SMS01BMS04B	14°22.254′ N	161°08.931′ E	1,381	1	0	42	42	34	81	0	crust(10),phos. conglo.(24)
13		02SMS01BMS04C	14°22.257′ N	161°08.958′ E	1,383	1	0	46	46	25	56	1	crust(8),cal. conglo.(17)
14	BMS05	02SMS01BMS05A	14°16.796′ N	160°58.451′ E	1,585	1	0	35	35	35	100	0	crust（10）,cal. conglo.（25）
15		02SMS01BMS05B	14°16.801′ N	160°58.481′ E	1,584	1	0	40	40	39	100	1	crust（9）,limestone（30）
16		02SMS01BMS05C	14°16.803′ N	160°58.508′ E	1,586	1	0	36	36	26	72	0	crust（10）,Cal. conglo.(8),limestone（8）
17		02SMS01LC15	14°17.195′ N	160°57.014′ E	1,542					155			foraminiferal sand（155）

cal.conglo.: calcareous conglomerate, phos.conglo:phosphoric conglomerate

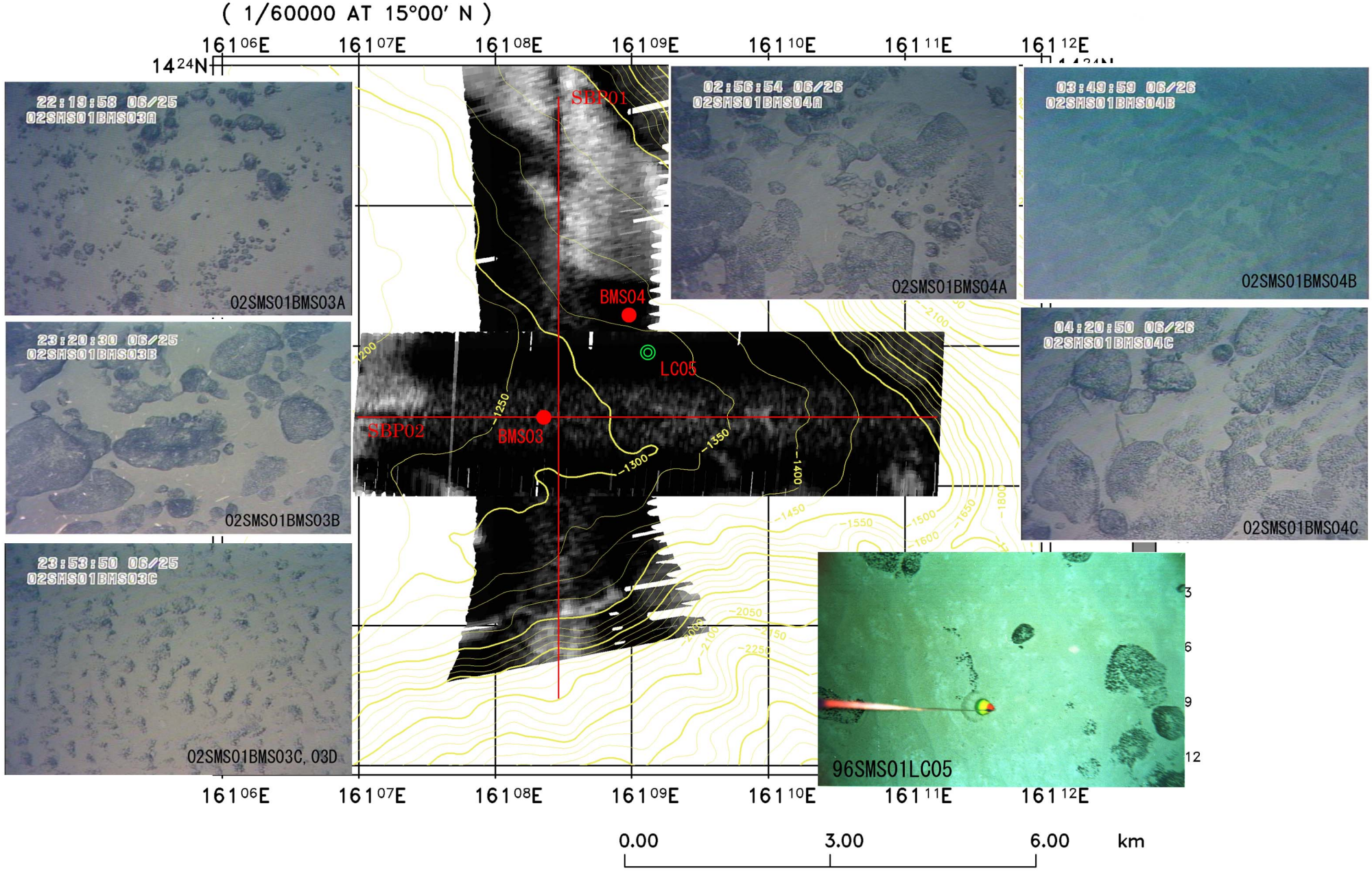


Figure 3-2-2-4 Acoustic Reflection Map of Track Lines SBP01 and SBP02

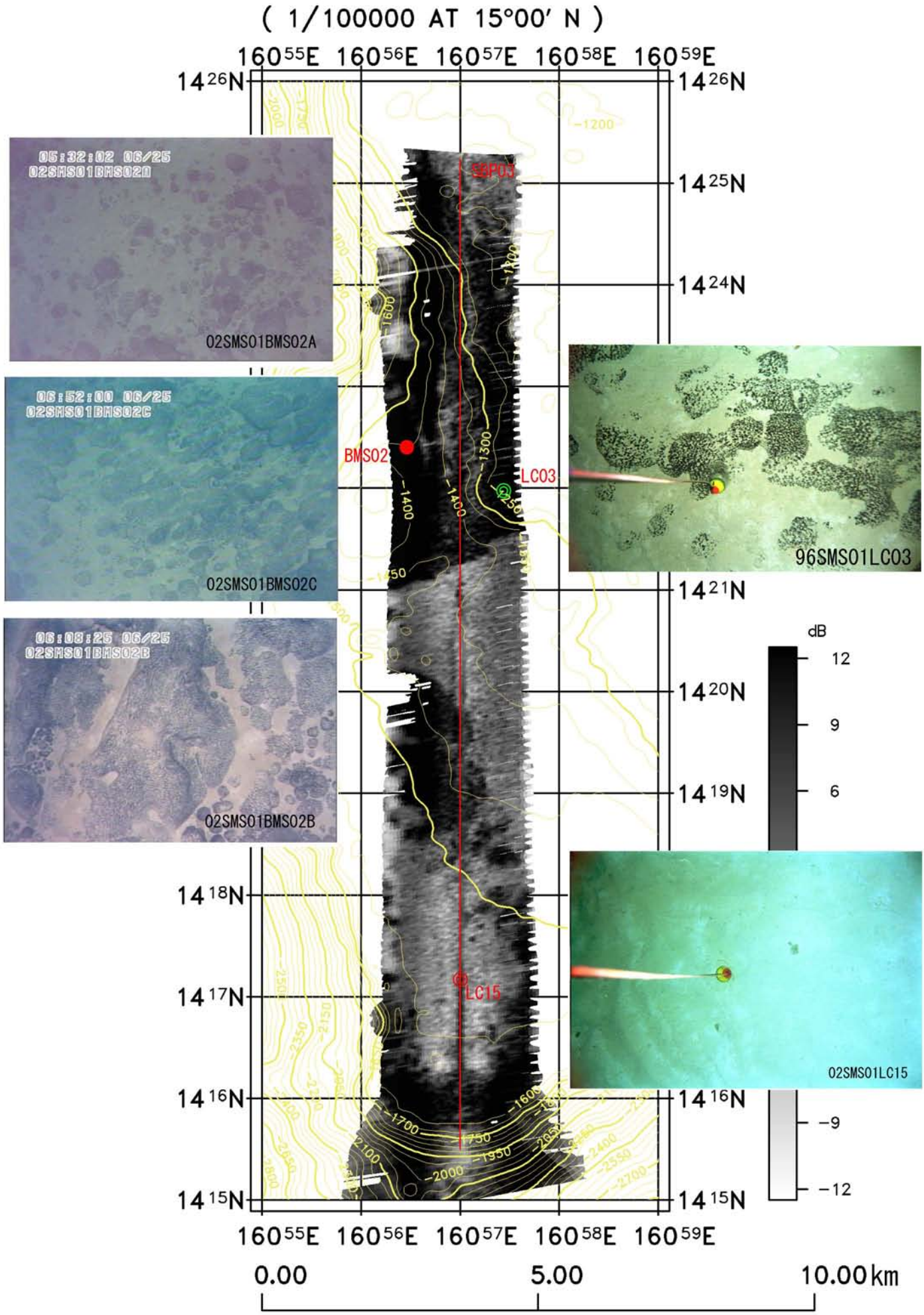


Figure 3-2-2-5 Acoustic Reflection Map of Track Line SBP03

3-2-2-1 02SMS01BMS01 Site

Drilling site: The 02SMS01BMS01 site is located at the southwestern part of the summit, and the site is lower part of the slope with the water depth of 1,400m to 1,300m, dividing two terraces. The drilling was aimed to understand the occurrence of cobalt crust at the summit area. According to the MBES acoustic map, the area of the water depth of 1,300m to 1,400m is covered by annular dark tone surrounding the summit. Drilling of three holes, A (drilling length of 37cm), C (40cm), and B (34cm), were conducted at 50m to 100m apart from east to west direction.

Circumstances of seafloor: The seafloor around the BMS01 site shows the surface composed of swelling crust of globular to ellipsoidal shape of diameter or long axis of 10cm to 50cm, and thin sediments covering partly the surface of the crust. The rate of exposure of the crust surface is 20 to 30%. The surface shows botryoidal texture. The seafloor at the drilling point A is positioned on the thin sediments between exposed rocks, and the point B and C are positioned on the margin of irregular shaped crust, and drilling was conducted on the little curved crust surface at both B and C points.

Cobalt crust: Cobalt crust was obtained at all the points A, B, and C. At the point A, two layers of crust of total thickness of 60mm are obtained. At B, the top 5cm is composed of cobalt crust, in more detail, the surface 15mm is pebble of cobalt crust, and beneath it is 10mm thick cobalt crust showing nodule like occurrence surrounding nucleus rock. At C, the crust develops from the surface to 5cm deep. Since the core is crushed and brecciated, the detail is not clear, but crust with a thickness of 50mm was assumed. Average thickness of cobalt crust at the BMS01 site becomes 45mm averaging the thickness of three core samples, and it becomes 55mm if point B, where nodule exists, is excluded.

Rock sample: At every A, B, C points, calcareous conglomerate occurs at the lower part of the cobalt crust, so that calcareous conglomerate is assumed to be distributed around the BMS01 site. The matrix of calcareous conglomerate consists of white limestone and it partly contains foraminifera fragments. The gravels in conglomerate are, brown to dark brown color, angular, 0.5cm to 8cm in size, basalts lacking phenochryst. Some of these basalt gravels are covered with manganese oxides of thickness of 1mm to 10mm, and thus it is assumed

that the formation of manganese oxides began preceding, or concurrently with, the formation of calcareous matrices.

3 - 2 - 2 - 2 02SMS01BMS02 Site

Drilling site: The BMS02 site is located at the west of the summit area at water depth of about 1,460m. At the southwestern part of the summit, the lower terrace extensively develops occupying the area of water depth of 1,400m to 1,600m. At the northern part of the terrace, there occurs comparatively wide dark tone area on the MBES acoustic image. In order to understand the occurrence of cobalt crust there, the drilling at the BMS02 site was conducted. Three holes of A (core length of 49cm), C (34cm), and B (35cm) were drilled from north to south direction.

Circumstances of seafloor: The seafloor around the point A and B shows similar in appearance, the exposed crust surface increases ruggedness and the surface appears globular to irregular shape, partly the surface is covered by sediments. The exposure rate of the crust is 20% to 30%. There exist sporadic nodules with diameter of several cm on the sediments. Around the point C, platy crust with comparatively flat surface develops with exposure rate of 40%. The surface is highly irregular at the point A and B, and comparatively flat at C.

Cobalt crust: Crust samples are obtained at all three points, though the occurrence is different each other. At the point A, there exists a nodule of diameter of 7cm with 30mm thick cobalt crust, covered by 4 cm thick sediments. From the occurrence, the nodule is likely to be one of gravel derived from calcareous conglomerate below. At the point B, the top sediment is 8cm thick, thicker than other two points. Covered by the cobalt crust of 2mm thick, there exists calcareous conglomerate containing gravels of nodules of 1cm to 3cm across with cobalt crust of 2mm to 10mm thick. At the point C, three-layered crust sample with thickness of 60mm was collected. It seems that when the top sediments become thicker, thinner the cobalt crust as observed at the point B. By simply averaging samples of three holes, thickness of the cobalt crust at the BM02 site becomes 31mm. But there is a tendency that the floor surface is flat and top sediments is thin, the thickness of the cobalt crust increases

Rock sample: The rock sample of the point A is calcareous conglomerate and the matrix is composed of white fine limestone. It contains 5mm to 30mm size brown, glassy basalt gravel and particles of manganese oxides of diameter of 1mm to 5mm, and some of basalt gravels are covered by manganese oxides of thickness of 1mm to 5 mm. At the point B, like the point A, top 16cm is calcareous conglomerate containing basalt gravel covered by manganese oxides. The lower part, the 4cm of the sample, is composed of yellowish gray tuffaceous sandstone. At the point C, there exists pale yellowish brown lapilli tuff containing fragments of volcanic rock. Accordingly, the BMS02 site is thought to be tuffaceous rock-dominant area with local distribution of calcareous conglomerate.

3 - 2 - 2 - 3 02SMS01BMS03 Site

Drilling site: At the east of the summit, the boundary of the upper terrace and the lower terrace becomes unclear, and it becomes an area of gentle, continuous slope of the water depth of 1,200m to 1,500m. The area is dark tone in the MBES acoustic image. The 02SMS01BMS03 site corresponds to the upper part of the gentle slope of the water depth of 1,290m, and the drilling was conducted to confirm the development of cobalt crust at the east of the summit. Three drill holes, A (drilling length of 49cm), B (36cm), and C (40cm), were drilled with the distance of 50m to 100m roughly from east to west direction. After the drilling at the point C, the point D (core length of 162cm) was drilled at the point 1m away form point C to confirm the characteristics of the bedrock.

Circumstances of seafloor: Seafloor around the drilling points differs from point to point. Around the point A, the exposure rate is comparatively poor, showing exposure rate of about 5%, comprising the surface of cobble crust of 10cm across and nodules are scattered over sediments. The point A is located on the sediments and gravel-like crusts scatter nearby. At the point B, crust of the rounded surface with globular to ellipsoidal shape of diameter or long axis of 10cm to 20cm, crops out with 20% to 90% of exposure rate. The drilling of point B was conducted on such cobalt crust surface. Around the points C and D, the surface of the cobalt crust is comparatively flat and platy crust exposes covered with thin sediments, and the convex surfaces of the cobalt crust top show directional alignment like a ripple mark. The drilling at the C and D points was done on the flat crust surface of such appearance.

Cobalt crust: At the point A, the surface is covered with 15cm, rather thick sediments, and calcareous conglomerate exists below it. The crust at the surface of conglomerate is thin, 3mm thick. At the point B, core sample is crushed and brecciated, thus the detail is not clear, however, cobalt crust of 20mm thick consisting of two layers assumed to exists. At the point C, two-layer structure cobalt crust of 100mm thick was collected. At the point D, core sample was crushed and brecciated, thus detail is not clear, but thickness of cobalt crust was assumed to be 130mm. At the point A of the BMS03 site as well as the BMS02 site, where the surface is covered with 15cm thick sediments, the development of the cobalt crust becomes poor, 3mm. Simply averaging core samples of A, B, and C, thickness of cobalt crust at the BMS03 site becomes 41mm.

Rock Sample: Calcareous conglomerate was collected from four points A, B, C, and D. The matrix of conglomerate consists of white to grayish white fine limestone, and includes brown, 2mm to 30mm across, sub-angular, glassy basalt fragments. Part of basalt fragments is coated with manganese oxides of about 1mm to 3mm in thickness. At the point B, there occur grayish brown tuffaceous sandstone beneath the calcareous conglomerate.

3 - 2 - 2 - 4 02SMS01BMS04 Site

Drilling site: The BMS04 site is located at the east of summit and about 3km northeast of the BMS03 site. There develop two terraces of the summit area and the slope zone of water depth of 1,380m to 1,400m divides both terraces. The BMS04 site is located at the lower part of the slope at water depth of 1,380m. The drilling was conducted to understand the development of cobalt crust at the east of the summit area. Three points A (core length of 71cm), B (42cm), and C (46cm), were selected to make triangle position each of them 50m to 100m apart.

Circumstances of seafloor: The seafloor circumstances at three points are similar. The exposed crust shows swelled globular to ellipsoidal shape but the ruggedness is small, and comparatively flat, platy cobalt crust exposes with exposure rate of 20% to 50%. Three holes were drilled on the flat platy surface, and point A shows a little inclined surface.

Cobalt Crust: Cobalt crust of 60mm, 100mm, 80mm thick were, respectively, collected at the points A, B, and C. The crust shows two-layer structure at the point A and C, and three-layer structure at the point B. The layers at C are horizontal but layers at the point A and B incline about 30 degrees to the horizontal plane. The drilling of the BMS04 site was conducted under similar seafloor circumstances and comparatively similar thickness of cobalt crusts were collected. The thickness of cobalt crust at the site is, from simple average of three samples, about 80mm.

Rock Sample: Calcareous conglomerate and phosphoric conglomerate that are deduced from limestone are sampled at the point A, B, and C. They include basalt and manganese oxides gravels of 1cm to 5cm across.

3 - 2 - 2 - 5 02SMS01BMS05 Site

Drilling site: The BMS05 site is located at southwestern part of the summit with water depth of 1,585m. The lower terrace of the summit is distributed at the area between water depth of 1,400m and 1,600m. The BMS05 site was selected to make clear the development of cobalt crust at the terrace. Drillings of points A (core length of 35cm), C (40cm), and B (36cm) were conducted from roughly west to east direction with the distance of about 50m.

Circumstances of seafloor: The seafloor at the points A and B are similar. The cobalt crust of 10cm to 30cm size, swelled, globular to ellipsoidal shape surface is distributed with exposure rate of 10% to 20%. Around the point C, the surface looks similar to the point A and B, but the exposure rate is higher, 70% to 80%. The crust surface shows platy appearance as if globular to ellipsoidal surface were jointed together. The point A is positioned on the periphery of the swelled cobalt crust and the point B and C are positioned on the boundary of swelled cobalt crust.

Cobalt Crust: Cobalt crusts with thickness of 100mm, 90mm, and 100mm were, respectively, collected at the points A, B, and C. At the point A, the cobalt crust shows two-layer structure, and at the point B and C, it shows three-layer structure. The layers are inclined 10 degrees to 30 degrees to the horizontal plane, reflecting the drilling point is positioned on the swelled surface or on

the boundary of the swelled crust. The exposure rate of the crust is little different at each point, however, seafloor circumstances are similar and cobalt crusts with similar thickness were obtained at the three points. The average thickness of the crust at this site is, by simply averaging three core samples, 97mm.

Rock Sample: Calcareous conglomerate and limestone samples were obtained from the points A, B, and C. At the point A, the sample is calcareous conglomerate composed of white, fine limestone matrix and dark gray to grayish brown pebbly basalt of size of 5mm to 50mm, and a part of pebbly basalt is covered by manganese oxides of several mms thick. At the point C, similar calcareous conglomerate is seen to continue 8cm beneath the cobalt crust, and it is succeeded by pale-brown, fossil shell-bearing limestone. At the point B, limestone occurs beneath the cobalt crust.

3 - 2 - 2 - 6 Sampling Results by LC

Only one LC sampling, 02SMS01LC15, was conducted at the MS01 seamount. The central area of the lower terrace at the southeastern part of the summit shows light tone in the MBES acoustic image, and the LC sampling was conducted to obtain the information of sediments. Foraminiferal sand with core length of 155cm was collected.

3 - 2 - 3 Geology

Rock samples and type of cobalt crust samples obtained by the survey of this year are shown together with results of previously year in Figure 3-2-3-1.

For characteristic rock samples, thin section observation, chemical analysis and fossil test were conducted and for unconsolidated sediments fossil identification was conducted.

3 - 2 - 3 - 1 Outline of Geology

Adding the information of previous year, samples obtained at the MS01 seamount are basalt, lapilli tuff, limestone, conglomerate, sandstone, mudstone, and foraminiferal sand together with cobalt crust.

At the seamount, conglomerates were collected from various points of the summit to the slope area. Particularly, at the every sampling points of the marginal area of the summit where the BMS survey was conducted, conglomerate containing basalt was obtained. Basalt was collected in part at the summit area, but almost all of samples

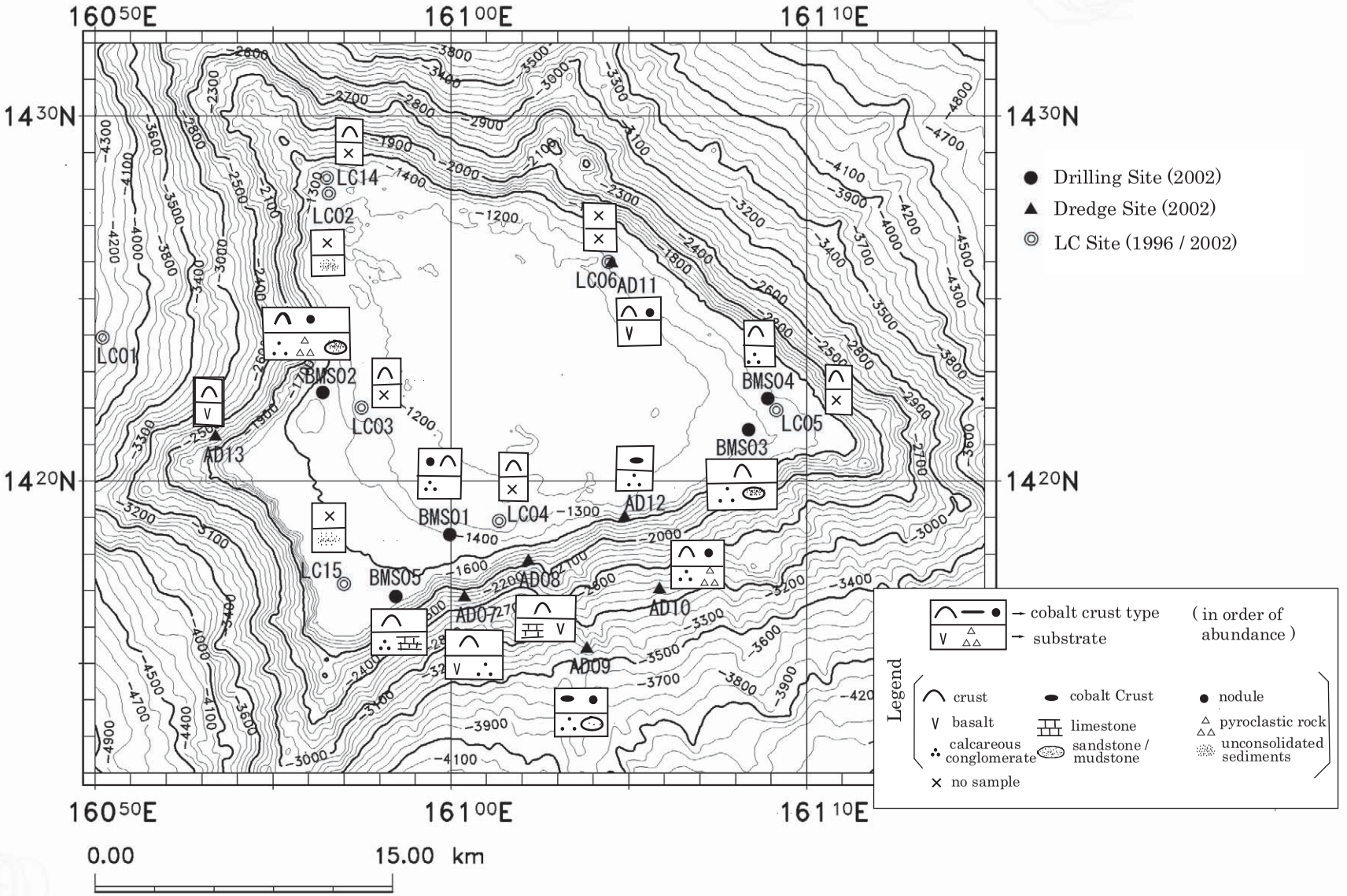


Figure 3-2-3-1 Distributions of Rock and Cobalt Crust in MS01 Seamount

were obtained by dredge at the upper part of the slope with limestone and conglomerate samples. Other than that, lapilli tuff, sandstone, and mudstone were collected from the limited points.

The distribution and characteristics of each type of rock are as follows.

Basalt: In the previous survey, basalt samples were obtained by dredging at three points of the upper part of the slope, and one point at the summit area. They show dark brown to brown in color, and they are fine grained, compact or porous rock. In the survey of this year, all the basalt samples are breccia derived from conglomerates. They resemble to the samples of previous year, showing dark brown to brown in color, glassy basalt lacking phenocryst.

Conglomerate: It is distributed widely from the summit to the slope. They are calcareous conglomerate, limestone deduced phosphoric conglomerate, some of which have sandy to muddy matrix. All of rock fragments are sub-angular basalt. In the drilling survey of this year, calcareous to phosphoric conglomerate was collected at all the sites. At the BMS03D site, all of the drilled cores of length of 1.62meters consisted of calcareous conglomerate and it is assumed rather thick. Whole conglomerate samples contain sub-angular basalt rock fragments of 5mm to 50mm across, and often coated with manganese oxides, so that the precipitation of manganese oxides is thought to have started before or during the formation of calcareous matrix.

Limestone: In the previous survey, only one pebbly limestone sample of few cm in size was obtained at the AD08. In the survey of this year, limestone sample was obtained only from the point B and C at the BMS05 site. Limestone of the point B contains fine clastic fragments, and limestone obtained at the point C is fossil bearing neritic limestone.

Lapilli tuff: Lapilli tuff was obtained only at two points, the AD10 point of the previous survey and the point C of BMS02 site. They are composed of pale yellowish brown matrix and contain 2mm to 10mm size basalt rock fragments.

Sandstone and Mudstone: In the previous survey, small amount of mudstone was collected at the AD09. This year, tuffaceous sandstone was collected at the lower part of calcareous conglomerate of the core sample of the BMS02B and BMS03B site.

At the MS01 seamount, there exists basalt to form basal part of the seamount but the surface is covered with calcareous to phosphoric conglomerate that contains rock fragments of basalt. After the formation of the seamount by basalt, part of basalt was brecciated or fragmented due to structural movement. Limestone is not so common, seen as part of matrix of conglomerate at most, and the seamount had been submerged in comparatively early stage. Calcareous and phosphoric conglomerate contain rock fragment of basalt covered by manganese oxides. As the surface of the conglomerates is covered by cobalt crust and thus the formation of cobalt crust had been started before the formation of calcareous matrix (limestone) and the growth of the crust continued afterward.

3 -2 - 3 - 2 Thin Section Observation

For the purpose of clarifying the characteristics of typical rock samples and determine the rock type of unknown rock due to alteration, microscopic observation was conducted. The description of the microscopic observation and the result are shown in Table3-2-3-1 and Appendix 6, and photographs of petrographic microscope are given in Appendix 7.

At the MS01 seamount, petrographic microscope observation of four samples, two basalt samples (BMS01CTS01, BMS03CTS01), one lapilli tuff (BMS02CT01), and one tuffaceous sandstone sample (BMS03BTS01), were made.

Of the two basalt samples, one is the sample obtained from the south of the summit (BMS01 point) and the other is obtained from the east of the summit (BMS 03 point). They are both rock fragments from calcareous limestone. The former one lacks phenocryst and the latter has phenocryst of olivine. Both show intersertal texture and amygdaloidal texture and plagioclase and olivine are observed in the groundmass. They are similar rock having plagioclase and olivine in groundmass and classified as alkali olivine basalt. Both are encountered alteration but the latter is heavily altered than the former. Both samples have been chemically analyzed.

BMS02CTS01 is a lapilli tuff with 60mm thick crust on the surface, and it is collected near the foot of the slope of 1,300m to 1,400m depth of the west of summit. It contains 2mm to 4mm olivine basalt fragments, and rarely associated with oolitic limestone of 0.5mm across, and it is tuffaceous to conglomeratic sandstone.

BMS03BTS01 seems tuffaceous sandstone obtained from the lower part of the calcareous conglomerate. It is heavily altered and groundmass is not recognizable, and composed of aggregate of glassy rock fragments of olivine basalt. It is considered to be altered hyaloclastite.

Table 3-2-3-1 Microscopic Observations for Rock Thin section of MS01 Seamount

Sample No.	Occurrence	Rock Type	Microscopic Observations
02SMS01BMS01C TS01 collected at 15-20cm	basalt pebble of 5cm across included in calcareous limestone. Chemical analysis (BMS01CCA01)	brown, compact, hard, phenocrysts of needle like plagioclase are scattered, partly porous.	**olivine basalt : partly vesicular,** amygdaloidal texture and aphyric, intersertal groundmass consists of plagioclase, olivine, glass, opaque minerals, olivine is completely replaced by chlorite and serpentinite.
02SMS01BMS02C TS01 collected at 20-25cm	bedrock covered by crust.	gray to pale brown color, porous filed by calcareous material, include detrital fragments.	**tuffaceous sandstone** : includes detrital fragments of vesicular basalt and oolitic limestone, matrix is filled by calcite.
02SMS01BMS03B TS01 collected at 17-20cm	pyroclastic rock occurs beneath calcareous conglomerate	pale brown, soft clayey rock with brown veins.	**hyaloclastite of olivine basalt** : detrital fragments consist of olivine basalt, volcanic glass is altered to paragonite, olivine is completely replaced to serpentinite.
02SMS01BMS03C TS01 collected at 31-35cm	basalt pebble of 3cm across included in calcareous limestone. Chemical analysis (BMS03CCA01)	brown, soft, olivine phenocryst is observed.	**olivine basalt** : intersertal and amygdaloidal texture, altered olivine phenocryst is observed, groundmass mainly consists of glass and subordinate plagioclase and olivine, strongly altered.

3 - 2 - 3 -3 Results of Petrochemical Analysis

Chemical analysis of basalt was conducted to make clear the igneous activity of the formation of the seamount. The methods applied and detection limit are shown in Appendix 8, and the results of the analysis is given in Table 3-2-3-2. On the basis of analysis, figures such as chondrite normalized pattern, spiderdigram, $MnO \times 10 - TiO_2 - P_2O_5 \times 10$, $Zr/4 - 2Nb - Y$, $Ti/1000 - V$, and $Nb/Zr - Ba/Zr$, were drawn and given in Appendix 9.

Two samples used for chemical analysis (BMS01CCA01, BMS03CCA01), are olivine basalt sampled at the southwestern part of the summit (BMS01 site) and sampled at the east of the summit (BMS03 site), and both are rocks fragments in calcareous conglomerate. Under microscope observation, alteration is rather strong on the BMS01CCA01 sample, and strong on the BMS03CCA01 sample.

Concerning major element, both samples show very high ratio of Fe_2O_3 to FeO, showing almost oxidized condition of Fe. Moreover, loss of ignition (LOI) is high showing 5.05% and 6.65%, and the yielding of clay minerals is assumed due to alteration. Generally speaking, average content of P_2O_5 of basalt is less than 0.5%, but the BMS01CCA01 sample shows 1.05%, and in case of the BMS03CCA01 sample, it shows very high content, 8.73%, suggesting the influence of phosphotization. As well as P_2O_5, the content of CaO of BMS03CCA01 is very high showing 17.39%, and also CO_2 content shows high, 1.39%, and this suggests the sample is encountered carbonitization. Major elements of the sample show rather big change due to alteration. On the other hand, the BMS01CCA01 sample shows comparatively weak alteration, and the chemical composition seems that the sample keeps good characteristics of the source igneous rocks. It shows Mg content of 3.54%, MgO/MgO + FeO* ratio of 0.265, a little low compared with that of average basalt, and shows slightly high content of $Na_2 + K_2O$, 5.34% and TiO2, 1.39%, suggesting the characteristics of slightly diferenciated alkaline rock.

In the diagram of chondrite normalized pattern (Appendix 9, Figure 1), the BMS03CCA01 sample shows negative anomaly of Ce, and generally high amount of heavy rare earth, suggesting the influence of phosphatization. The BMS01CCA01 sample shows alkaline rock pattern, and it shows similar pattern to alkaline basalt of the seamounts of the Marshall Islands reported by Davis et al. (1989).

In the spiderdigram (Appendix 9, Figure 2), the BMS03CCA01 sample has abnormally high P and Y, suggesting the influence of phosphatization, but except that, it shows similar pattern as the BMS01CCA01 sample. That is, two samples have several tens of times higher content of elements such as K, Rb, Ba, Nb compared with

Table 3-2-3-2 Results of Petrochemical Analysis of MS01 Seamount

		02SMS01	02SMS01
		BMS01C CA01	BMS03C CA01
		Olivine Basalt	Olivine Basalt
SiO_2	%	47.41	34.89
TiO_2	%	1.93	1.60
Al_2O_3	%	16.85	12.94
Fe_2O_3	%	10.32	9.62
FeO	%	0.55	0.55
MnO	%	0.10	0.06
MgO	%	3.54	2.05
CaO	%	6.83	17.39
Na_2O	%	4.06	3.08
K_2O	%	1.28	1.33
P_2O_5	%	1.05	8.73
CO_2	%	0.11	1.39
H_2O^+	%	1.99	2.18
H_2O^-	%	2.35	1.83
LOI	%	5.05	6.65
TOTAL	%	98.97	98.89
FeO*	%	9.84	9.84
Mg#		0.265	0.172
Rb	ppm	30.6	35.7
Sr	ppm	340	693
Ba	ppm	187	141
Zr	ppm	100	99
V	ppm	154	205
Nb	ppm	27.2	24.6
Y	ppm	29.2	123.0
La	ppm	19.05	70.63
Ce	ppm	29.06	38.04
Pr	ppm	3.97	6.92
Nd	ppm	17.95	31.24
Sm	ppm	4.37	6.49
Eu	ppm	1.76	2.30
Gd	ppm	4.91	8.74
Tb	ppm	0.92	1.42
Dy	ppm	4.63	7.93
Ho	ppm	0.84	1.78
Er	ppm	2.34	5.37
Tm	ppm	0.31	0.80
Yb	ppm	1.86	4.32
Lu	ppm	0.26	0.69

Mid Ocean Ridge Basalt (MORB) and they show similar pattern such as alkaline basalt and oceanic islands alkaline basalt with high content of such elements.

Rock discrimination diagram was drawn using trace elements, which are thought to be resistive to alteration. In the $MnO \times 10 - TiO_2 - P_2O_5 \times 10$ diagram(Appendix 9, Figure 3), the sample of the MS01 seamount is plotted in the domain of P_2O_5 rich alkaline basalt of oceanic island, however, the BMS03CCA01 is seemed the sample of markedly enriched P_2O_5 by phosphotization. In the Zr/4－2Nb－Y diagram(Appendix 9, Figure 4), and in the Ti/1000－V diagram (Appendix 9, Figure 5), the BMS03CCA01 sample is plotted in or near the oceanic island alkaline basalt domain, but the BMS01CCA01sample is plotted far from this domain. Accordingly, it is thought that the BMS01CCA01sample originally had chemical composition similar to oceanic island basalt, but its chemical composition had been changed by alteration with phosphotization.

The ratio of incompatible element is known to originate the composition of mantle of magma generation, and it is reported that basalts in the SOPITA (South Pacific Isotopic and Thermal Anomaly) region show Ba/Nb ratio of 4 to 10 (Davis et al, 1989, Christie et al., 1995, Appendix 9 Figure 6). Two samples obtained from the MS01 seamount show the Ba/ Nb ratio of about six, and it is within the range of Ba/Nb ratio of the SOPTIA region.

3 - 2 - 3 - 4　Results of Fossil Test

Using sediments obtained by the LC sampling and sedimentary rocks obtained by the drilling, fossil tests were done to make clear the age of sediments and sedimentary rocks and their sedimentary environment. The results of the fossil test of sediments and rock samples are shown in Table3-2-3-3 and Table 3-2-3-4. The list of fossils, photographs of typical fossils are shown in Appendix 10.

(1) Fossil of unconsolidated sediments

Examined samples are two samples of the LC15, and it was collected at the lower terrace of the southeastern part of the summit. The sampling site is located in the light tone area of the MBES acoustic image, and assumed the surface to be covered with comparatively thick sediments. Of the obtained foraminiferal sand of core length of 155cm, two samples, 35cm to 40cm (FS01) and 125cm to 130cm (FS02), were tested for the fossil identification.

The ages of the deposition of sediments of two samples, assumed from the foraminiferal and nanno plankton fossil species, are late Pleistocene (0.12 – 0.16 Ma) for

Table 3-2-3-3 Results of Fossil Test of Sediments of MS01 Seamount

Site	Depth (m)	Sample No.	Sampling Depth (cm)	Type of Sample	Age Foraminifera	Age Nannofossil	Foraminifera	Nannofossil
02SMS01 LC15	1,542	FS01	35-40	Foraminiferal sand	middle - late Pleistocene (0.12－0.65Ma)	late Pleistocene (0－0.16Ma)	FS01 includes *Globigerinoides ruber* (pink) and *Globorotalia truncatulinoides, and Globorotalia tosaensis was not observed. Geological age of FS01 is middle-late Pleistocene* (probably 0.12～0.65Ma). FS02 includes *G. tosaensis, Globigerinoides fistulosus was not observed.* Geological age of FS02 is early Pleistocene (0.65～1.6Ma). FS01 includes reworked fossils (*G. obliquus*).	Occurrences *of Emiliania huxleyi* and no existence of *Helicosphaera inversa* suggests fossil zone NN21 of Martini(1971), correspond to 0-0.16Ma, younger than Standard Horizon 1.
		FS02	125-130	Foraminiferal sand	early Pleistocene (0.65－1.6Ma)	middle Pleistocene (0.51－0.85Ma)		Occurrences of *G. parallela and Pseudoemiliania lacunosa* and no existence of *R. asanoi* suggests Standard Horizon 4～5, 0.51～0.85Ma, upper NN19 zone.

Table 3-2-3-4 Results of Fossil Test of Rocks of MS01 Seamount

Site	Depth (m)	Sample No.	Sampling Depth (cm)	Topographic Division	Type of Sample	Rock Name	Remarks	Geological Age	
								neritic	pelagic
02SMS01 BMS01B	1,385	FR01	5-20	SW. Summit	Calcareous conglomerate covered by crust, pebbles of basalt and Mn oxides fragments are included.	foraminiferal wackestone	Includes fragments of basalt and Mn oxides, equigranular cements between fragments suggest diagenesis by terrestrial water, planktonic foraminifera ,*T. topilensis,* corresponds to P12-P14 and geological age is middle Eocene.	—	middle Eocene
02SMS01 BMS03A	1,286	FR01	23-40	E. Summit	Calcareous conglomerate covered by crust, pebbles of basalt with Mn oxides on surface are included.	foraminiferal packstone	Reworked foraminifer fossils are included, planktonic foraminifera ,*T. topilensis*, corresponds to P12-P14 and geological age is middle Eocene.	—	middle Eocene
02SMS01 BMS05C	1,586	FR01	15-26	SW. Summit Edge	Consists of calcareous limestone of upper part and reefal limestone of lower part, covered by crust.	bioclastic packstone	upper part：foraminiferal limestone, planktonic foraminifera ,T. topilensis, corresponds to P12-P14 and geological age is middle Eocene. lower part: reefal limestone, includes fossils such as coral, microencruster, miliolinid.	Cretaceous	middle Eocene

FS01 and middle Pleistocene (0.65 – 0.85 Ma) for FS02. Dissolution on fossil foraminiferal shell was observed in FS01, and there is the mixture of fossil fauna by rework. From this fact, the sedimentary environment at the time of the deposition is assumed to have been, put under the influence of bottom current, slow in sedimentation speed, and in the condition to allow the deposition of allocthonous sediments. From fossil foraminiferal species, it is assumed that the sedimentary environment had been geographically in sub-tropical province. The samples lack benthonic foraminiferal fossil and thus, paleo-water depth cannot be specified, it might be 800m to 2,500m. The deposition speed is calculated 2.05mm/1,000years, and this is rather slow as the deposition speed of calcareous sediments.

(2) Fossil test of rock sample

The sample tested are three sample, BMS01BF01, BMS03AFR01, and BMS05CFR01, obtained at the southwestern part of the summit, eastern part of the summit, and the southwestern margin of the summit, respectively. All of the samples are calcareous conglomerate including cobbles of basalt covered by manganese oxides and fragments of manganese oxides. The BMS01BF01 and the BMS05CFR01 sample are covered by crust of thickness of 25mm and 100mm respectively, but the BMS03AFR01 sample is covered with sediments of 15cm in thickness, and the thickness of the crust is thin, 3mm. The detail of the fossil test is shown in Appendix 10.

The BMS05CFR01 sample is constituted of two types of limestone, that is, the upper part is foraminiferal limestone and the lower part is reef limestone. The BMS01BFR01 and BMS03AFR01 sample are foraminiferal limestone. The reef limestone includes fossils of pachyodont bivalves and *microencruster*, and thought it had been deposited in Cretaceous Era, and the foraminiferal limestone is considered to have been deposited in middle Eocene time because it contains *T. topilensis*. The foraminiferal limestone includes volcanic rocks and manganese oxides, and it is observed that the interstitial part of the limestone grain had been encountered diagenesis by terrestrial water.

From the result of fossil test, the geologic history of the MS01 seamount is thought as follow.

In Cretaceous Era, the seamount had been exposed on the surface up to the position near the sample point of BMS05C (near the water depth of 1,400m to 1,600m today), and the reef had been formed around the seamount and limestone had deposited. After that, the seamount had submerged, and in middle Miocene time, the point of BMS01B and BMS03A had been submerged to such environment to permit the deposition of

foraminiferal limestone of pelagic environment. As the foraminiferal limestone includes volcanic rocks, it is assumed that the summit of the seamount had been exposed over the sea surface (water table is assumed to be present water depth of 1,200m position). Foraminiferal limestone includes manganese oxides, and it is assumed that the formation of cobalt crust had been started under such environment. After that, the seamount uplifted at least the level of the BMS05C site (water depth of 1,586m) appeared over the sea surface, and again submerged to the present position. The foraminiferal limestone is covered by cobalt crust, and thus the main stage of the formation of the cobalt crust was middle Eocene and later. According to Watkins et al. (1995), the formation of cobalt crust around this area is thought to be Eocene to Oligocene.

3 - 2 - 4 Occurrence of Cobalt Crust

At the MS01 seamount, as the survey of 1996, samplings at 14 points (AD: 7points, LC: 7points) were conducted and cobalt crust was collected at 11points. The average thickness of 36mm and average grade of Co0.67% were suggested for the cobalt crust of MS01 seamount.

In the survey of this year, drilling was conducted at five sites in the area of gentle slope and expected exposure of cobalt crust, taking into account of easier exploitation in the future. The purpose of the survey is to understand the natures of cobalt crust distribution in the summit area and in different water depths, and to clarify horizontal continuity and occurrences under sediment coverage.

3 - 2 - 4 - 1 Distribution

(1) Thickness of cobalt crust

Results of sampling made in the survey of 1996 and this year are given in Table 3-2-4-1 and Table 3-2-4-2. The distribution of cobalt crust is given in Figure 3-2-4-1. The thickness of cobalt crust relative to water depth and thickness of sediments are given in Figure 3-2-4-2 and Figure 3-2-4-3.

In the survey of 1996, the survey was conducted centering the summit area and south slop of the seamount, and crust, cobble crust and small amount of nodules were obtained. The average thickness of the cobalt crust, excluding nodule, at each sampling points ranges from 20mm to 75mm, and the average thickness of 11 points is 36mm. At the summit area shallower than the water depth of 1,600m, the average thickness varies with a little broad range, from 30mm to 75mm.The average thickness of the slope area of the water depth greater than 1,600m shows comparatively narrow range, 20mm

Table 3-2-4-1 Cobalt Crust Samples Colleceted in Previous Year in MS01 Seamount

No.	Sampling No.	Depth (m)	Topographic Division	Cobalt Crust Type	Crust			Cobble Crust			Total		
					Amount (kg)	Max. (mm)	Min. (mm)	Amount (kg)	Max. (mm)	Min. (mm)	Amount (kg)	Max. (mm)	Min. (mm)
1	96SMS01LC01	4,267	W.lower slop										
2	96SMS01LC02	1,195	NE.summit edge										
3	96SMS01LC03	1,226	W.summit edge	crust fragment	0.86	80	50				0.86	80	50
4	96SMS01LC04	1,218	S.summit edge	crust fragment	0.46	80	75				0.46	80	75
5	96SMS01LC05	1,317	E.summit edge	crust fragment	0.77	45	30				0.77	45	30
6	96SMS01LC06	1,234	NE.summit edge										
7	96SMS01AD07	2,218	S.middle slop	crust	1.40	75	20				1.40	75	20
8	96SMS01AD08	1,815	S.upper slop	crust	2.49	50	30				2.49	50	30
9	96SMS01AD09	3,284	S.lower slop	cobble crust、nodule				21.10	35	20	21.10	35	20
10	96SMS01AD10	2,825	S.lower slop	crust、nodule	30.90	50	40				30.90	50	40
11	96SMS01AD11	1,242	NE.summit edge	crust、nodule	25.50	90	40				25.50	90	40
12	96SMS01AD12	1,408	S.summit edge	cobble crust				220.00	70	40	220.00	70	40
13	96SMS01AD13	2,398	W.middle slop	crust	0.64	30	20				0.64	30	20
14	96SMS01LC14	1,231	NW.summit edge	crust fragment	0.22	40	30				0.22	40	30
					Max.	90	75	Max.	70	40	Max.	90	75
					Ave.	60	37	Ave.	53	30	Ave.	59	36
											Ave (summit)		44
											Ave.(slop)		26

Table 3-2-4-2 Sampling Results of Cobalt Crust in MS01 Seamount

No.	Drill Site	Drill Point	Depth (m)	Topographic Division	Sediments (m)	Cobalt Crust	Thickness (mm)	layers	Drill Core	Ave. Thickness (mm)	Bedrock	Seafloor
1	BMS01	02SMS01BMS01A	1,388	SW.summit	4	crust	60	2		45	cal. congl.	boulder like surface、ER.20%
2		02SMS01BMS01B	1,385	SW.summit	0	crust、nodule	25	2			cal. congl.	boulder like surface、ER.25%
3		02SMS01BMS01C	1,382	SW.summit	0	crust	50		crushed		cal. congl.	boulder like surface、ER.30%
4	BMS02	02SMS01BMS02A	1,461	W.summit edge	4	nodule	30	1		31	cal. congl.	boulder like surface、ER.20%
5		02SMS01BMS02B	1,457	W.summit edge	8	crust	2	1			cal. congl.、sandstone	boulder like surface、ER.30%
6		02SMS01BMS02C	1,457	W.summit edge	4	crust	60	2			lapilli tuff	relatively flat、ER.40%
7	BMS03	02SMS01BMS03A	1,286	E.summit	15	crust	3	1		41	cal. congl.	boulder like surface、ER.5%
8		02SMS01BMS03B	1,287	E.summit	0	crust	20	2	crushed		cal. congl.、sandstone	boulder like surface、ER.20-90%
9		02SMS01BMS03C	1,287	E.summit	1	crust	100	2			cal. congl.	flat、ER.10%
10		02SMS01BMS03D*	1,287	E.summit	0	crust	130		crushed		cal. congl.	flat、ER.10%
11	BMS04	02SMS01BMS04A	1,376	E.summit	4	crust	60	2		80	phos. Congl.	flat、ER.20-40%
12		02SMS01BMS04B	1,381	E.summit	0	crust	100	3			phos. Congl.	flat、ER.50%
13		02SMS01BMS04C	1,383	E.summit	1	crust	80	2			cal. congl.	boulder like surface、ER.40%
14	BMS05	02SMS01BMS05A	1,585	SW.summit edge	0	crust	100	2		97	cal. congl.	boulder like surface、ER.20%
15		02SMS01BMS05B	1,584	SW.summit edge	1	crust	90	3			limestone	boulder like surface、ER.10%
16		02SMS01BMS05C	1,586	SW.summit edge	0	crust	100	3			cal. congl.,limestone	boulder like surface、ER.70-80%
						Max.	130			97		
						Min.	2			31		
						Ave. (summit)	63			59		
						S.D.	39			28		

*BMS03D is located close to BMS03C, therefore this hole is not included for average calculation.
cal.congl.: calcareous conglomerate,phos congl.: phosphoric conglomerate ER.: exposure rate

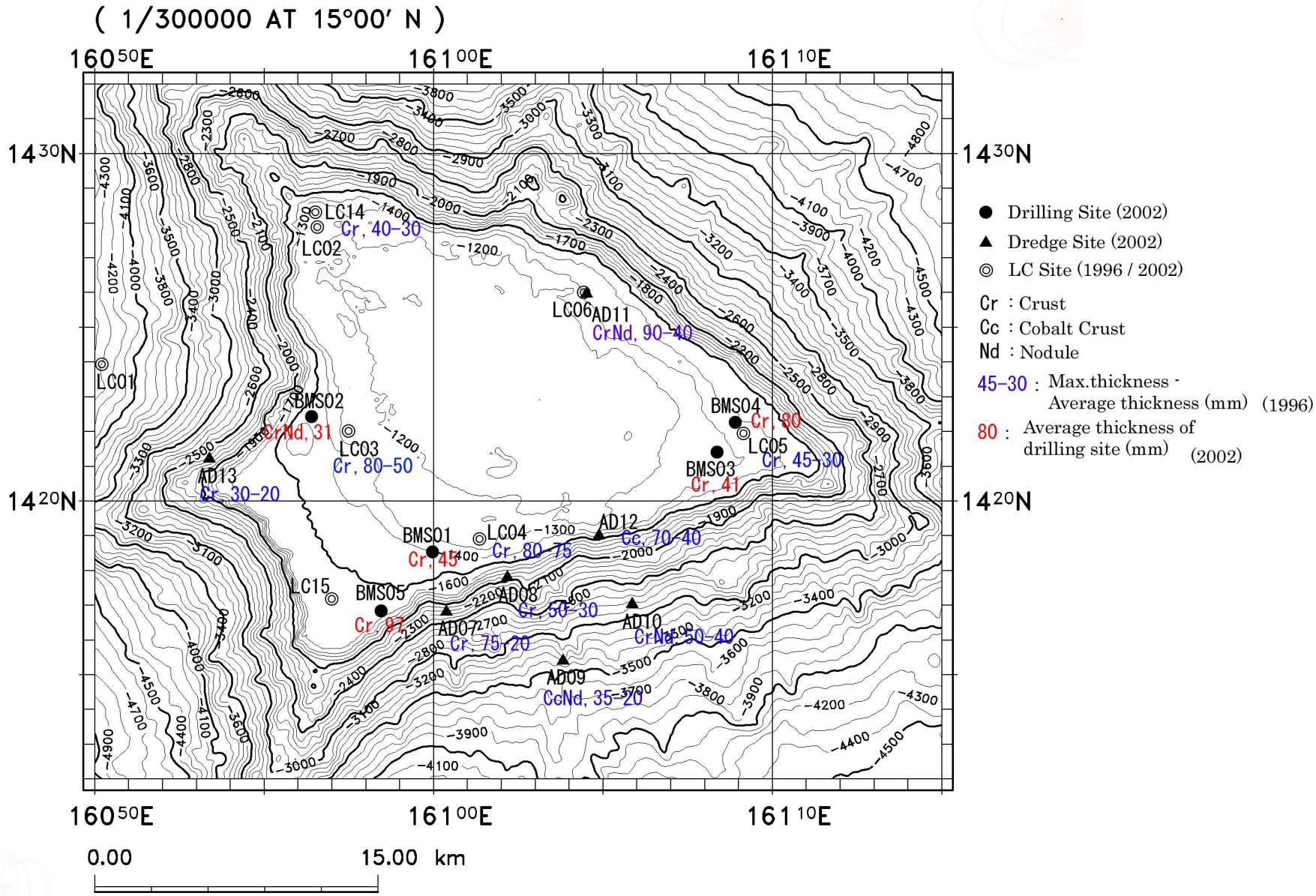


Figure 3-2-4-1 Thickness and Type of Cobalt Crust in MS01 Seamount

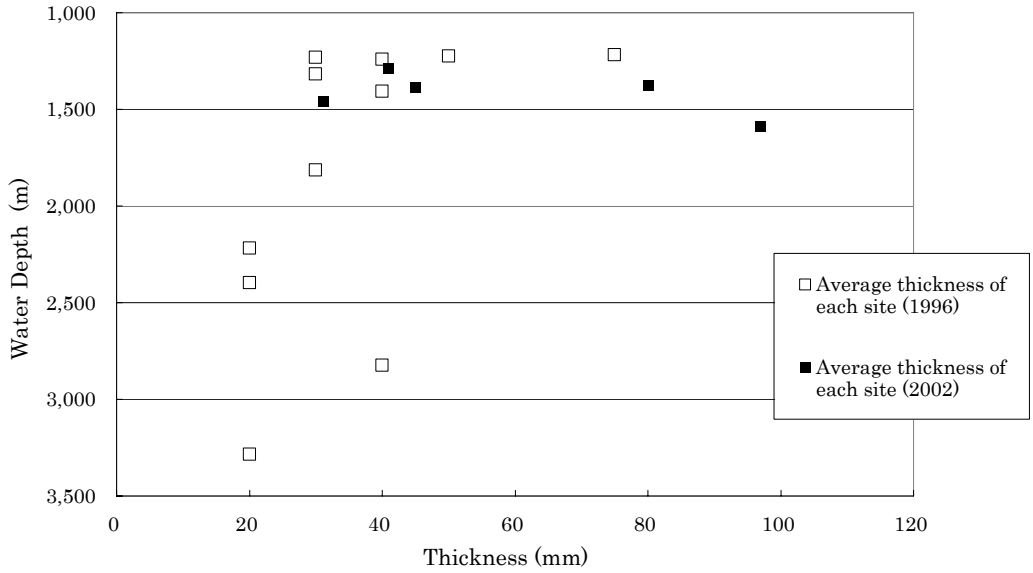


Figure 3-2-4-2 Thickness of Cobalt Crust and Water Depth of MS01 Seamount

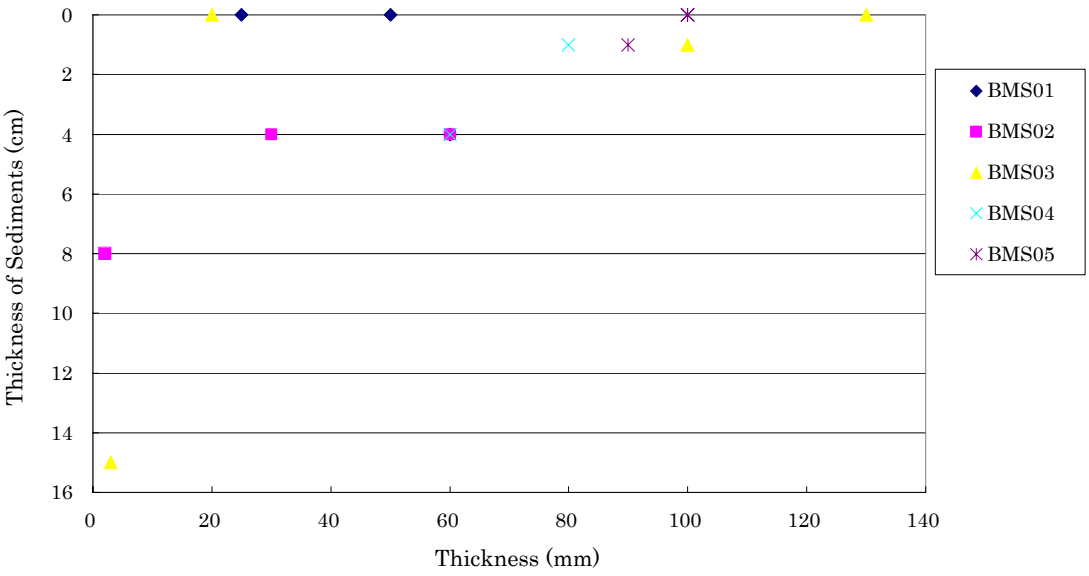


Figure 3-2-4-3 Thickness of Cobalt Crust and Sediment of MS01 Seamount

to 40mm, and there is no example in the slope area to show the thickness greater than 50mm as seen at the summit area.

In the survey of this year, the thickness of the cobalt crust at each drilling point of 16 holes exhibits wide range from 2mm to 130mm, and the average thickness is 63mm. The variation of thickness of different drilling points at the same site is, small at the BMS04 site and BMS05 site, but big at the BMS02 site and BMS03 site, showing 2mm to 60mm and 3mm to 130mm, respectively.

It is observed in Table 3-2-4-2 and Figure 3-2-4-3 that the thickness of cobalt crust becomes very thin when the surface is overlain by unconsolidated sediments, as shown by the BMS02B point and the BMS03A point with 8cm thick sediments and 2mm thick crust, and 15cm thick sediments and 3mm thick crust, respectively. Moreover, the point where the thickness of the cobalt crust attains thicker than 50mm, the thickness of unconsolidated sediments is less than 4cm. The points where cobalt crust directly expose and lack unconsolidated sediments, the thickness of cobalt crust varies from 2mm to 130mm, and the variation of thickness reflects factors other than the thickness of sediment cover. The thickness of the cobalt crust varies from point to point to some extent and it also seems to be controlled by the present thickness of unconsolidated sediments.

Average thickness of the cobalt crust at each site is obtained by simply averaging the thickness of cobalt crust of three to four drilling points of each drilling site. The average thickness of five sites, BMS01 to BMS05, varies 37mm to 97mm, and the average thickness of five sites is 59mm. The results of previous survey showed that the average thickness of each of six sites on the summit area ranged from 35mm to 75mm. As for as summit area is concern, similar thickness of cobalt crust was obtained compared with last year. .

Concerning the circumstances of the seafloor and the thickness of cobalt crust, no clear relation was observed. Generally speaking, if the seafloor is flat, thick cobalt crust exists, and in case the seafloor shows rugged irregular surface or aggregates of boulder like surface, both thick and thin cases exist.

(2) Layered structure of cobalt crust

In order to understand the historical sequence of cobalt crust growth, cobalt crust was described subdividing the layers of cobalt crust into seven types on the basis of visual appearance. Each layer of the layer structure is called layer1, layer2, layer3, and so on, from the outer (close to the surface) side to the inner side close to bedrock. The subdivision of the layer is shown in Figure 3-2-4-4.

Drilling Site	BMS01			BMS02			BMS03				BMS04			BMS05		
	A	B	C	A	B	C	A	B	C	D	A	B	C	A	B	C
Water Depth (m)	1, 388	1, 385	1, 382	1, 461	1, 457	1, 457	1, 286	1, 287	1,287	1,287	1,376	1,381	1,383	1,585	1,584	1,586
Thickness of Sediments (cm)	4	0	0	4	8	4	15	0	1	0	4	0	1	0	1	0
Type	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust
Thickness (mm)	60	25	50	30	2	60	3	20	100	130	60	100	80	100	90	100
Bedrock	Calca. Conglo.	Calca. Conglo.	Calca. Conglo.	Calca. Conglo.	Calca. Conglo.	Lapilli tuff	Calca. Conglo.	Calca. Conglo.	Calca. Conglo.	Calca. Conglo.	Phosph. Conglo.	Phosph. Conglo.	Calca. Conglo.	Calca. Conglo.	Limesto -ne	Calca. Conglo.
Layers	2	2	unknown	1	1	3	1	unknown	2	unknown	2	3	2	2	3	3

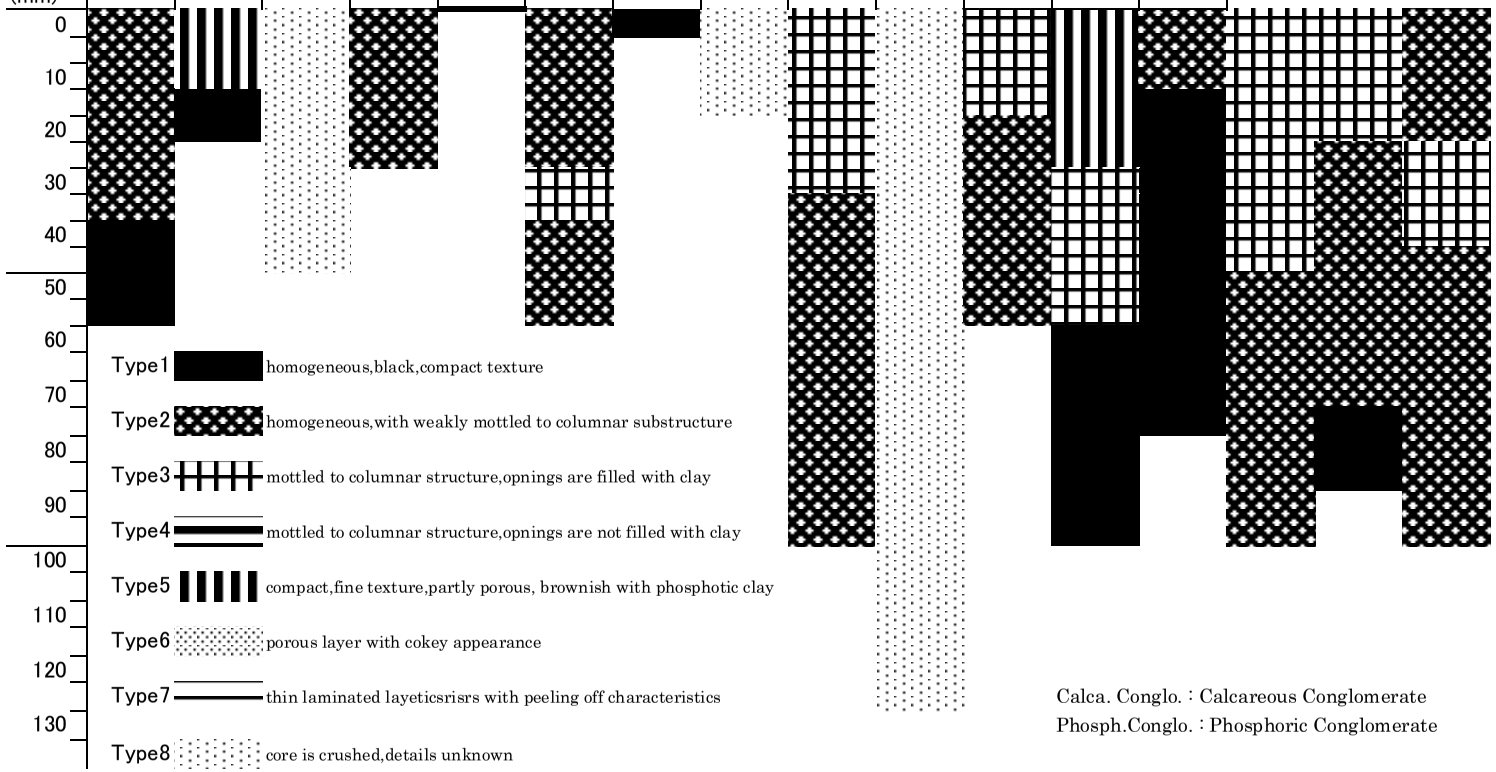


Figure 3-2-4-4 Layer Subdivision of Cobalt Crust of MS01 Seamount

The cobalt crust of the MS01 seamount, if cobalt crust is thin, shows a single layer structure, but other than that, it shows two to three layered structures. On the same site, no systematic relation is seen, except few cases such as the BMS05 site and etc., showing similar layer structure among the cobalt crust of each point. Generally, the innermost layer shows black, fine layer (Type 1), or weakly mottled to columnar layer structure (Type 2), and there is tendency that the layer becomes porous toward outside, the outermost layer is composed of mottled to columnar structure (Type 2 or Type 3).

(3) Distribution of cobalt crust

At the summit area of the MS01 seamount, the area of exposed bedrock is distributed from the margin of the summit to the central part of the summit ranging the water depth of 1,200m to 1,600m. Drilling of the five sites was conducted in this exposed area. The cobalt crust samples were collected at all of the five drilling sites with average thickness varying from 31mm to 97mm. The average thickness of five sites is 59mm.In the survey of this year, drilling was not conducted at the north side of the summit area, but as the results of the survey previously done, the maximum thickness of 40mm and 90mm are obtained from the AD11 point and LC14 point at the north part of summit area, and thus cobalt crust with an average thickness of about 6cm (59mm) is assumed to be distributed covering whole area from the margin of the summit to the summit between the water depth of 1,200m to 1,600m.

The drilling sites of this year are distributed from marginal area to the summit with the water depth of 1,287m to 1,586m, and the difference of water depths of each points within the site are small. For this reason, the relation of water depth and thickness of cobalt crust was not firmed from the result of this year. From the results of the previous survey as is shown in Figure 3-2-4-2, the samples obtained from the slope area of the water depth of deeper than 1,600m have cobalt crust with thickness of 20mm to 40mm, and there are no such samples with average thickness over 40mm collected from the slope area. There is a tendency that with the increase of the water depths, the decrease of the thickness of the cobalt crust.

In order to confirm the horizontal succession of the development of the cobalt crust, drilling survey was planned in the east part of the summit area with the water depth of 1,200m to 1,500m, but it was canceled due to bad weather. The drilling survey to confirm the occurrences of cobalt crust beneath sediments coverage was also hampered by bad weather. But as seen at the BMS02B site and the BMS03A site, the cobalt crust covered by the sediments is evidently thin compared with the cobalt crust obtained at exposed area nearby. There is a possibility that the thickness of cobalt crust at the area

covered by sediments becomes poor compared with the area where the cobalt crust exposes on the surface.

3 - 2 - 4 - 2 Result of Chemical Analysis

Chemical analyses for 31 samples (bulk sample:15, layer by layer sample:16) obtained by the drilling survey at the MS01 seamount was conducted. A total of 32 elements including 22 elements of Co, Ni, Cu, Mn, Fe, Pb, Zn, Ti, Mo, V, Si, Al, Ca, K, P, Ba, Sr, Pt, LOI, H_2O^+, $H_2O^-$and 14 rare earth elements, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, were analyzed. The analytical methods and the results are given in Appendix 8 and 11.

(1) Bulk sample

The statistical values of each elements and major metal elements including Pt of the bulk analysis are shown in Table 3-2-4-3 and Table 3-2-4-4. The histogram of the bulk analysis and the scattergram adding the result of 1996 are given in Figure 3-2-4-5 and Figure 3-2-4-6.

The content of Co in the 15 bulk samples are 0.27% to 0.76%, mainly 0.40% to 0.50%. Ni and Cu are 0.44% to 0.82% and 0.09% to 0.18% respectively showing narrow dispersion pattern. The content of Mn and Fe are 16.34% to 25.94% and 8.40% to 15.10% and generally show scattered pattern. The content of Pt is 0.61ppm to 1.30ppm. The differences of grade among each point in a drill site (e.g. A. B, C) are comparatively small, so that average grade of drilling site (e. g. BMS01) was obtained by averaging grade of each point.

The average chemical content of the cobalt crust at the MS01 seamount obtained by the survey of this year, is Co: 0.44%, Ni: 0.65%, Cu:0. 12%, Mn: 20.71%, Fe: 11.69%, and Pt:0. 87ppm. Compared with the results of 1996, the content of Co and Fe are low, and Pt is high. There is no marked difference in Ni, Cu, and Mn. Compared with the average of the Central Pacific crust (Hein et al., 1992), Co is low and Pt is high.

In the scattergram, the positive correlation is observed for Co-Mn, and Co-Fe, and negative correlation for Co-Pt. There is no marked relation between water depth vs. Co content and average thickness vs. Co.

Other than above elements, the average content of metal elements, Pb, Zn, and Mo shows 0.12%, 0.09%, and 0.06%, respectively. The content of Ca and P shows wide range with 6.49% to 17.09% and 1.96% to 5.74%, and both elements show very good correlation.

On the rare earth elements of the bulk sample, the average ΣREE is 1,800ppm,

Table 3-2-4-3 Chemical Characteristics of Cobalt Crust of MS01 Seamount

	Co %	Ni %	Cu %	Mn %	Fe %	Mn/Fe	Pb %	Zn %	Ti %	Mo %	V %	Si %	Al %	Ca %	Na %	K %	P %	Ba %	Sr %	Pt ppm
Max.	0.76	0.82	0.18	25.94	15.10	2.21	0.14	0.10	1.00	0.07	0.07	3.68	1.11	17.09	1.78	0.59	5.74	0.24	0.16	1.30
Min.	0.27	0.44	0.09	16.34	8.40	1.35	0.08	0.07	0.51	0.05	0.05	1.02	0.42	6.49	1.37	0.36	1.96	0.16	0.14	0.61
Ave.	0.44	0.65	0.12	20.71	11.69	1.81	0.12	0.09	0.75	0.06	0.06	2.18	0.74	11.20	1.57	0.48	3.71	0.20	0.15	0.87
S.D.	0.12	0.11	0.03	2.83	2.30	0.31	0.02	0.01	0.13	0.01	0.01	0.84	0.25	3.25	0.11	0.07	1.16	0.02	0.01	0.22
C.V.	0.27	0.17	0.23	0.14	0.20	0.17	0.15	0.08	0.18	0.17	0.09	0.38	0.34	0.29	0.07	0.15	0.31	0.10	0.05	0.25

	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	ΣREE ppm
Max.	568	1330	65.8	314.0	53.0	15.7	82.4	11.3	75.2	17.8	55.3	7.5	45.5	7.8	2424.3
Min.	237	659	32.7	144.5	27.2	7.7	38.8	5.5	33.6	7.9	24.4	3.5	22.7	3.7	1414.2
Ave.	328	1001	42.3	195.1	35.0	10.1	51.7	7.2	45.8	10.7	33.7	4.7	29.8	5.0	1800.3
S.D.	98	182	9.1	46.7	7.0	2.2	12.4	1.6	11.8	2.9	9.2	1.2	6.9	1.2	319.2
C.V.	0.30	0.18	0.22	0.24	0.20	0.22	0.24	0.23	0.26	0.27	0.27	0.26	0.23	0.25	0.18

N=15
(bulk samples)

Table 3-2-4-4 Grade of Cobalt Crust of MS01 Seamount

	Drill Site	Drill Point	Depth (m)	Thickness (mm)	Co %	Ni %	Cu %	Mn%	Fe %	Mn/Fe	Pt ppm	Ave. Depth (m)	Max. Thickness (mm)	Ave. Thickness (mm)	Ave. Co %	Ave. Ni%	Ave. Cu%	Ave. Mn %	Ave. Fe%	Ave. Fe/Mn	Ave. Pt ppm
1	BMS01	A	1, 388	60	0. 43	0. 70	0. 13	19. 44	12. 60	1. 54	0. 80	1, 385	60	45	0. 39	0. 74	0. 14	20. 29	10. 53	1. 97	0. 84
2		B	1, 385	25	0. 34	0. 82	0. 18	18. 20	8. 50	2. 14	0. 85										
3		C	1, 382	50	0. 41	0. 70	0. 11	23. 23	10. 50	2. 21	0. 86										
4	BMS02	A	1, 461	30	0. 30	0. 52	0. 11	16. 57	8. 60	1. 93	1. 10	1, 458	60	31	0. 30	0. 55	0. 12	16. 67	9. 53	1. 78	1. 15
5		B	1, 457	10	0. 27	0. 68	0. 15	16. 34	8. 40	1. 95	1. 30										
6		C	1, 457	60	0. 32	0. 44	0. 09	17. 11	11. 60	1. 48	1. 05										
7	BMS04	B	1, 287	20	0. 44	0. 81	0. 13	22. 53	10. 60	2. 13	0. 79	1, 287	130	41	0. 49	0. 73	0. 10	23. 13	11. 97	1. 96	0. 77
8		C	1, 287	100	0. 55	0. 71	0. 09	23. 77	14. 00	1. 70	0. 83										
9		D	1, 287	130	0. 48	0. 69	0. 09	23. 08	11. 30	2. 04	0. 69										
10	BMS05	A	1, 376	60	0. 42	0. 66	0. 10	20. 52	10. 40	1. 97	0. 78	1, 380	100	80	0. 55	0. 68	0. 10	22. 95	11. 50	1. 99	0. 66
11		B	1, 381	100	0. 76	0. 73	0. 09	25. 94	12. 80	2. 03	0. 61										
12		C	1, 383	80	0. 47	0. 66	0. 10	22. 38	11. 30	1. 98	0. 61										
13	BMS06	A	1, 585	100	0. 45	0. 57	0. 15	20. 98	15. 10	1. 39	0. 92	1, 585	100	97	0. 44	0. 53	0. 13	20. 52	14. 93	1. 37	0. 95
14		B	1, 584	90	0. 40	0. 52	0. 12	20. 21	14. 60	1. 38	0. 64										
15		C	1, 586	100	0. 48	0. 51	0. 13	20. 36	15. 10	1. 35	1. 28										
		Samples	15	15	15	15	15	15	15	15		5	5	5	5	5	5	5	5	5	
		Max.	130	0. 76	0. 82	0. 18	25. 94	15. 10	2. 21	1. 30		130	97	0. 55	0. 74	0. 14	23. 13	14. 93	1. 99	1. 15	
		Mini.	10	0. 27	0. 44	0. 09	16. 34	8. 40	1. 35	0. 61		60	31	0. 30	0. 53	0. 10	16. 67	9. 53	1. 37	0. 66	
		Ave.	68	0. 44	0. 65	0. 12	20. 71	11. 69	1. 81	0. 87		90	59	0. 44	0. 65	0. 12	20. 71	11. 69	1. 81	0. 87	
		S.D.	36	0. 12	0. 11	0. 03	2. 83	2. 30	0. 31	0. 22		30	28	0. 10	0. 10	0. 02	2. 61	2. 04	0. 26	0. 19	
		C.V.	0. 53	0. 27	0. 17	0. 23	0. 14	0. 20	0. 17	0. 25		0. 33	0. 48	0. 22	0. 15	0. 17	0. 13	0. 17	0. 14	0. 21	
								Results of 1998			Samples	10	10	12	12	12	12	12	12	11	
											Ave.	65	37	0. 66	0. 61	0. 13	22. 82	14. 44	1. 62	0. 40	
								Ave. Central Pacific *			Samples			308	311	265	311	311	311	29	
											Ave.			0. 79	0. 47	0. 12	23. 00	15. 70	1. 39	0. 24	

*Average value of the Central Pacific Crust (Hein et al. 1992)

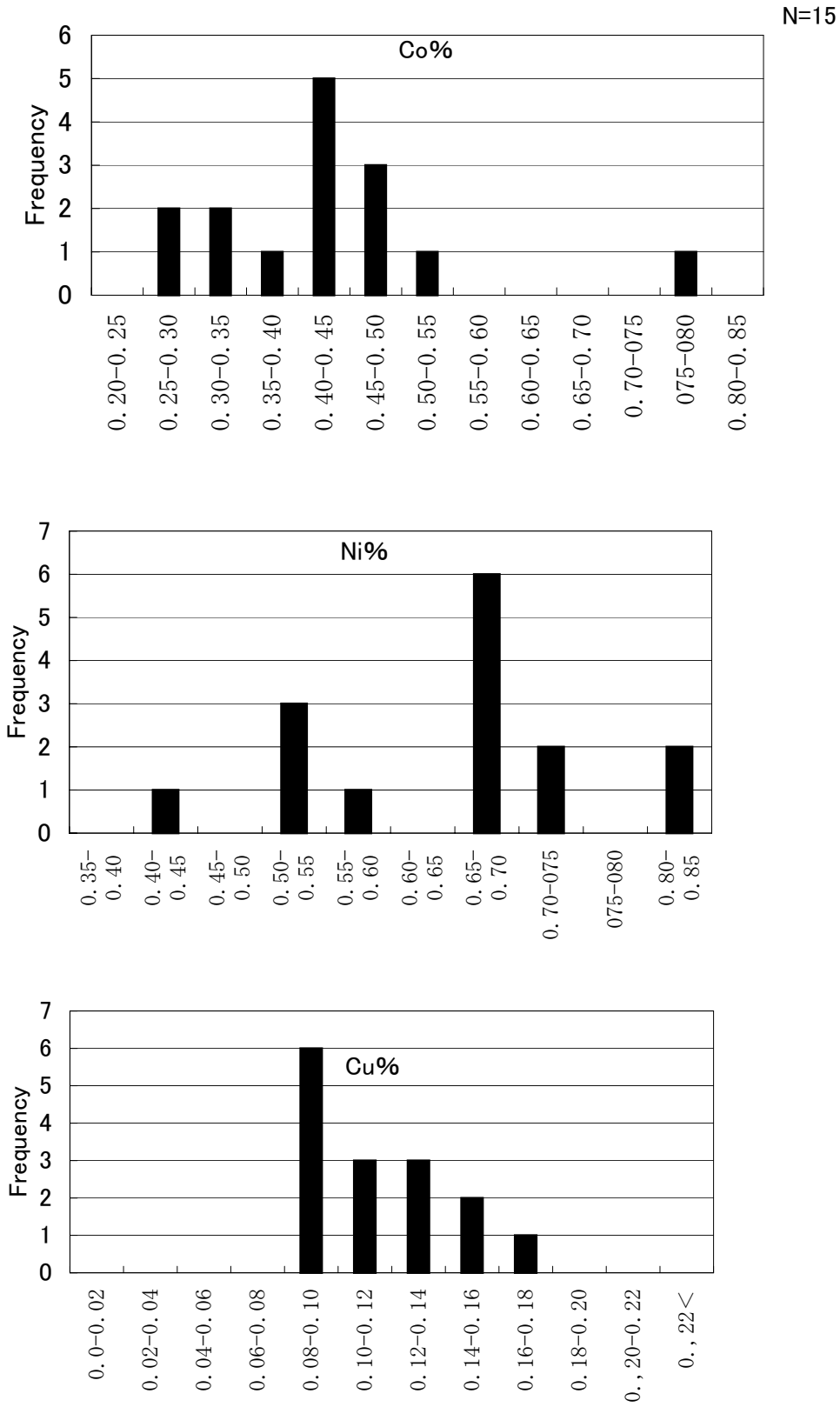


Figure 3-2-4-5 Assay Results Histogram of MS01 Seamount (1/2)

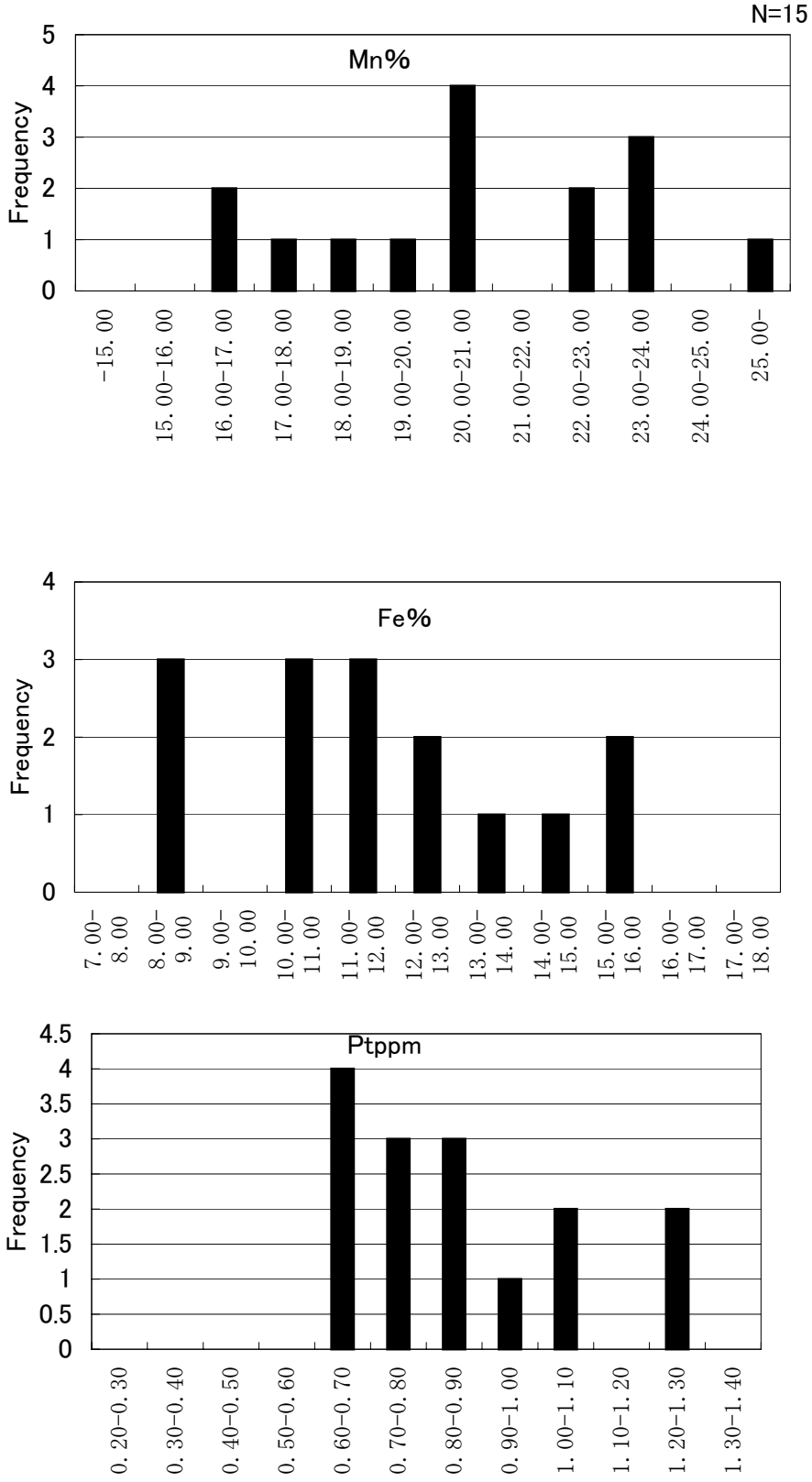


Figure 3-2-4-5 Assay Results Histogram of MS01 Seamount (2/2)

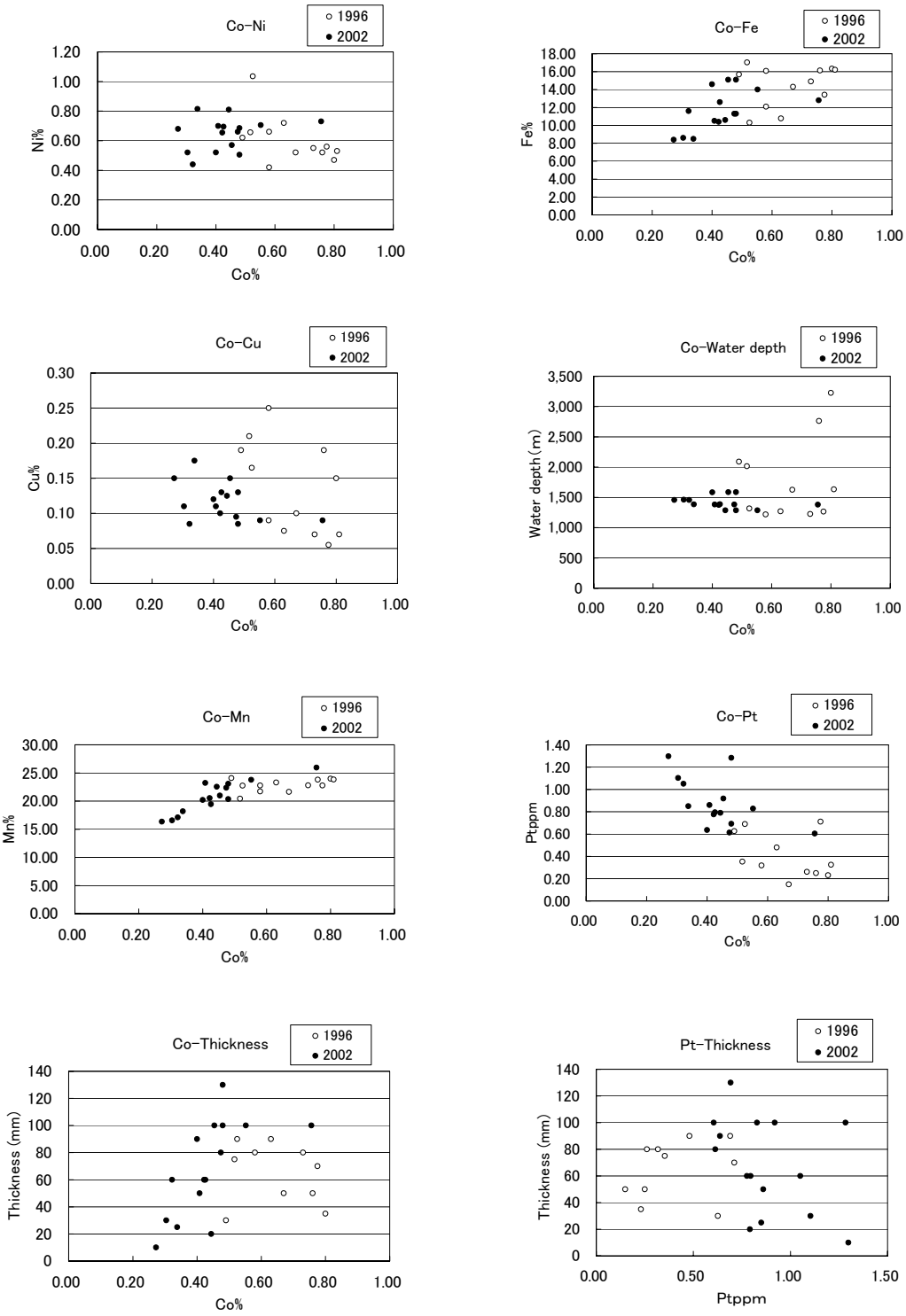


Figure 3-2-4-6　Dispersion Diagram of Assay Results of MS01 Seamount

and it has broad range, 1,414 ppm to 2,424ppm. This is due to the variation of Ce from 659ppm to 1,330ppm. In the North American standard shale normalized diagram, it shows flat pattern, and concentration of 4 to 10 times with positive anomaly of Ce. This pattern is similar to that of hydrogenetic crust of the seamounts in the Pacific region (Usui and Someya, 1997).

(2) Layer-by-Layer Sample

For the cobalt crust sample whose section surface shows clear layer structure, and each layer has sufficient amount of substance for the chemical analysis, layer-by-layer samples for chemical analysis were prepared. The statistical values of layer-by-layer analysis is shown in Table 3-2-4-5.

At the MS01 seamount, there are two-layer and three-layer structures samples. The average layer-by-layer contents of Co, in layer1, layer2, and layer3 are, 0.65%, 0.47%, and 0.45%, respectively. The layer1 is higher in Co than layer2 and 3, and it shows a tendency that the Co content decreases from the outside to inside. On the other hand, Ni shows reverse relation with Co. Mn does not show clear relation, but Fe decreases from outside to inside, so that Mn/Fe increases from outside to inside. The chemical properties related to the layer structure of the cobalt crust at the MS01 seamount are, from the view point of decrease of Co and increase of Mn/Fe from outside to inside, similar to that of cobalt-rich crust of Ogasawara Seamount and that of South Torishima area (Usui et al., 1987, Tokai Univ., CoRMC Survey Mission ed., 1990).

For other elements, Ca and P are low at layer1, and markedly increase at layer2 and layer3, and average of Ca is 3.20% at layer1, and it becomes 12.06% at layer3. The averages of P are, layer1, 0.79% and layer3, 4.06%. This suggests that inner layers include more impure substance other than Mn and Fe. Pt does not show clear characteristics.

(3) Grade and thickness

The distribution of grade of the cobalt crust at each sampling site is shown in Figure 3-2-4-7 as well as the thickness of the cobalt crust. The thickness of the cobalt crust of the 1996 survey, obtained by dredging and LC sampling, is shown by the maximum thickness of each site.

As the results of the survey of this year, the average grades of the cobalt crust obtained from the five sites at the summit area by the drilling are Co content of 0.30% to 0.55 % and average grade of them becomes 0.44%. There is no specific relation on the distribution of the Co grade and cobalt crust with Co grade of 0.44% is considered to be

Table 3-2-4-5 Results of Layer-by-Layer Analysis of Cobalt Crust of MS01 Seamont

		Co %	Ni %	Cu %	Mn %	Fe %	Mn/Fe	Pt ppm	Ca %	P %
layer1	samples	6	6	6	6	6	6	5	6	6
	Max.	0.98	0.61	0.12	25.32	19.20	1.46	1.00	6.47	2.00
	Min.	0.52	0.48	0.06	20.67	14.30	1.17	0.18	2.37	0.44
	Ave.	0.65	0.53	0.09	22.95	17.47	1.32	0.66	3.20	0.79
	S.D	0.18	0.05	0.02	1.57	1.70	0.12	0.34	1.61	0.60
	C.V.	0.27	0.09	0.24	0.07	0.10	0.09	0.51	0.50	0.75
layer2	samples	6	6	6	6	6	6	6	6	6
	Max.	0.75	0.76	0.14	24.55	18.20	2.56	0.84	15.19	5.26
	Min.	0.34	0.45	0.09	19.13	8.30	1.19	0.61	2.28	0.40
	Ave.	0.47	0.57	0.10	21.51	12.92	1.80	0.71	9.53	3.14
	S.D	0.15	0.12	0.02	1.99	3.96	0.57	0.10	5.70	2.15
	C.V.	0.33	0.21	0.22	0.09	0.31	0.32	0.14	0.60	0.68
layer3	samples	3	3	3	3	3	3	2	3	3
	Max.	0.64	0.81	0.14	25.17	13.00	2.62	0.74	14.17	4.86
	Min.	0.35	0.49	0.09	19.36	8.60	1.49	0.58	10.41	3.35
	Ave.	0.45	0.70	0.11	22.35	10.60	2.19	0.66	12.06	4.06
	S.D	0.17	0.18	0.02	2.91	2.23	0.61	0.11	1.92	0.76
	C.V.	0.37	0.26	0.20	0.13	0.21	0.28	0.17	0.16	0.19

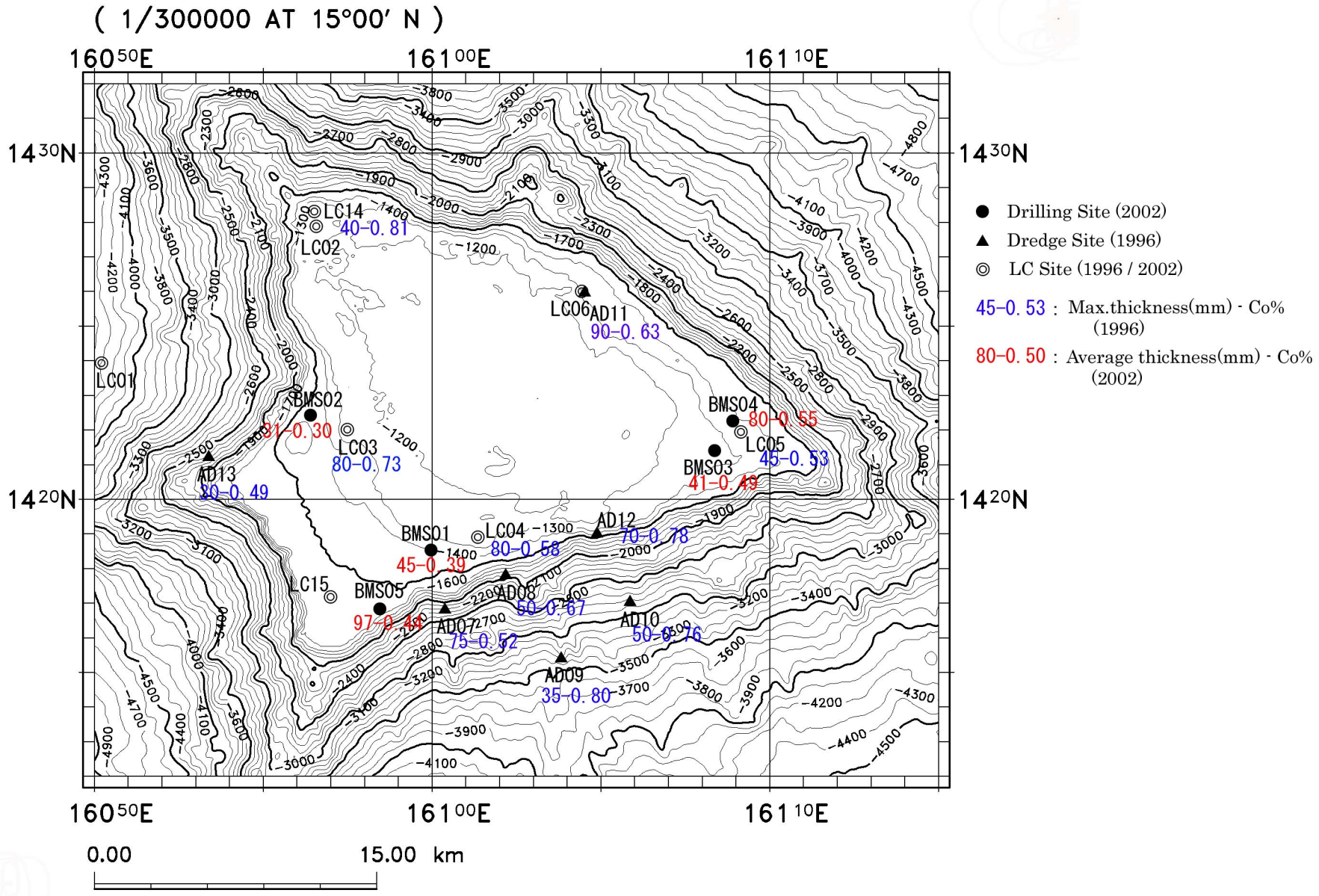


Figure 3-2-4-7 Co Grade and Thickness of Cobalt Crust in MS01 Seamount

widely distributed in the summit area. The thickness of the cobalt crust at the five sites show a wide ranges, 31mm to 97mm, and the average thickness of them is 59mm.

As the result of the 1996 survey, the average Co grade of 0.66% was obtained and this is higher than the result of this year. One of the possible reasons for this is that dredge and LC samplings collected incomplete cobalt crust samples dominated by outer layer during the survey of 1996. As shown in the layer-by-layer analysis result, the grade of Co of the outermost layer is high. The grade of Co calculated only from the outermost layer of this year becomes 0.65%.

As for the thickness of cobalt crust of 1996 survey, average thickness of MS01 seamount becomes 65mm by averaging the maximum thickness of each site. This figure is close to that of this year survey.

3 – 3 MS11 Seamount

In the survey of 1998, acoustic survey including MBES, dredging, and LC sampling were conducted at the MS11 seamount. In this year, supplementary acoustic survey taking supplementary track line for the purpose of the improvement of the accuracy of topographic map and drilling by the BMS and LC sampling were conducted..

3 – 3 – 1 Topography and Circumstances of Seafloor

Acoustic survey of the seamount had been conducted in 1998, and thus newly obtained information by the acoustic survey of this year are limited. The bathymetric map and the acoustic reflection intensity map of MBES are shown in Figure 3-3-1-1 and Figure 3-3-1-2.

3 – 3 – 1 – 1 Topography

The MS11 seamount is situated about 100km east of the Anewetak Atoll centering 10° 54' N, 161° 28'E and situated on the same plateau as Anewetak Atoll. It is a flat summit seamount with dome shape stricture of 700m high on the summit. The shallowest water depth is 1,495m. The summit area shows rectangular shape with long axis of N-S direction and covered widely with unconsolidated sediments. The water depth at the base of the seamount is 3,800m to 4,000m, and relative height from the base to the summit is only about 2,700m. The horizontal extent of the seamount of shallower than the water depth of 3,000m is 28km x 45km.

At the slope area, terrace like flat areas extend toward northwest, northeast, and southeast directions occupying the water depth zone of 2,500m to 3,000m. Of them, flat area of the northeast forms a saddle like topography and it continues to seamounts located in the north of this seamount. There develop many pinnacles on the saddle, and the ups and downs of the topography are conspicuous. West and northeast sides of the seamount are parallel to long axis direction of the seamount, NNW-SSE direction, and are quite linear.

3 - 3 - 1 - 2 Circumstances of Seafloor

The summit area of the seamount shows dome like topography, with relative height of 700m from the margin of the shoulder to the top. The light tone of the MBES acoustic image extends widely over the summit area reflecting the distribution of unconsolidated sediments. At the margin of the summit area, the dark tone in the acoustic image, suggesting the exposure of rocks, is observed at the topographic high along the shoulder part of the margin of the summit and at pinnacles. At the north of the summit, a little

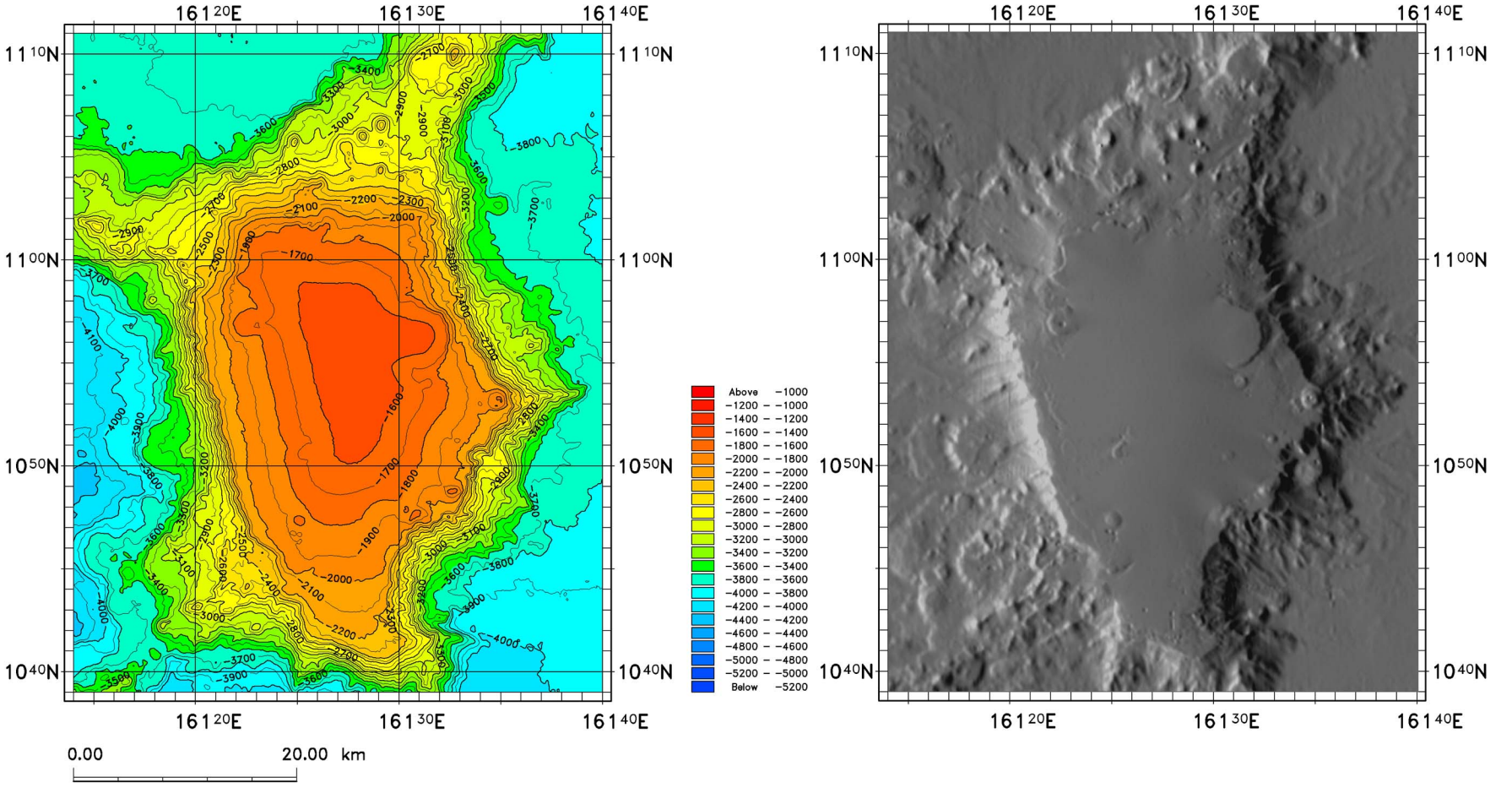


Figure 3-3-1-1 Bathymetric Map and Shaded Map of MS11 Seamount

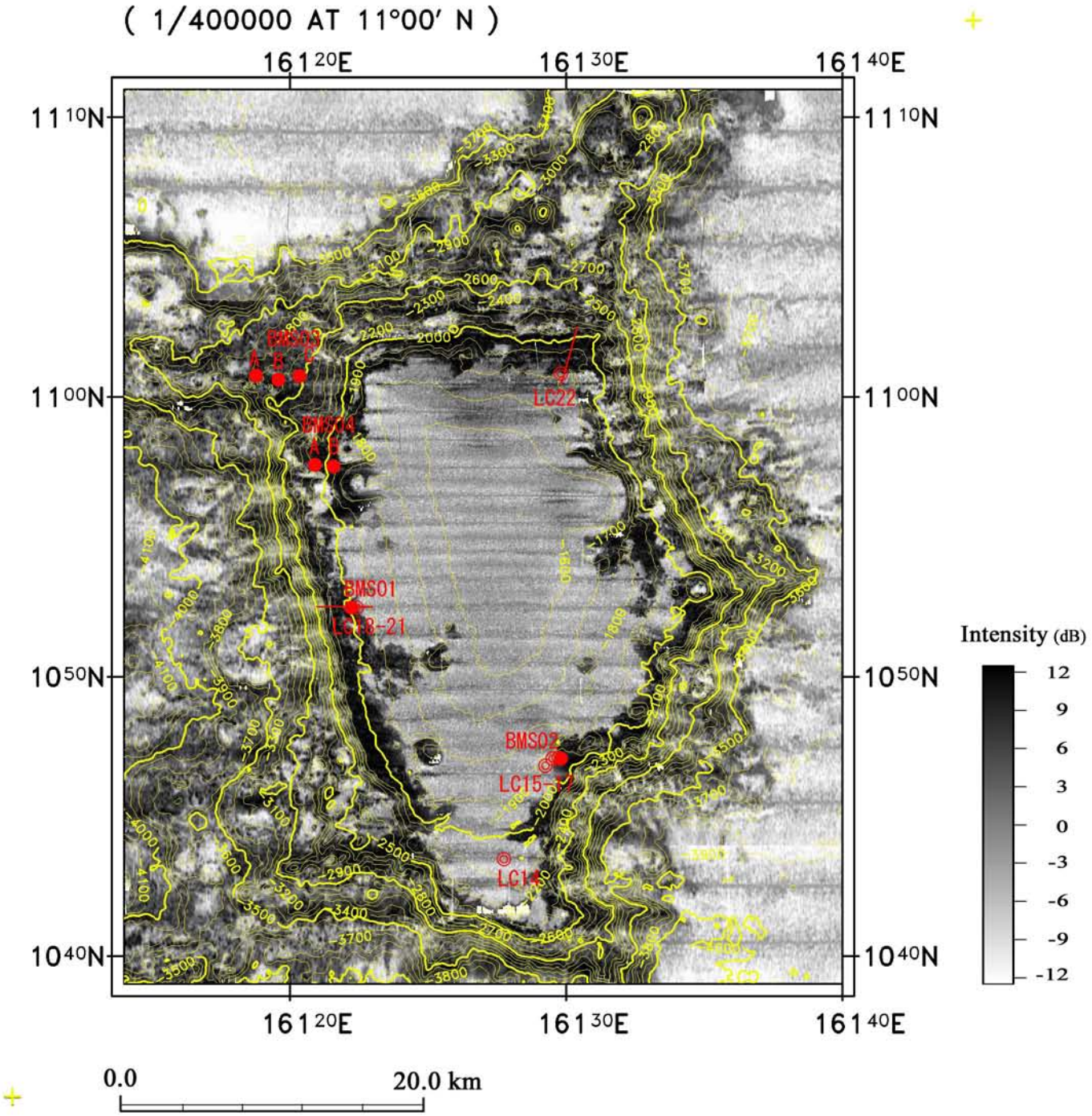


Figure 3-3-1-2 Acoustic Reflection Intensity Distribution of MS11 Seamount

dark area with the middle tone MBES image, suggesting the distribution of coarse grain unconsolidated sediments or nodules, is observed.

From the shoulder of the margin of the summit to the upper slope, there is a distribution of dark tone area, showing high reflection intensity. Also at the slope, light and dark tone portion corresponding to ridges and valleys, are seen, and the tone becomes lighter from the middle part of the slope to the lower part, suggesting the deposition of unconsolidated sediments become thicker. Particularly, the base topography of the seamount at the northeast and the southeast is quite flat, and acoustic intensity is very low, and it is assumed the area is covered with thick unconsolidated sediments.

According to the SBP survey conducted in 1998, the summit area is widely covered with unconsolidated sediments, and the thickest part is assumed to reach more than 100m in thickness. As a whole, the sediments are thick at the south side, and the area from 10° 50' N to south, it attains over 90m. At the summit area, there develop pinnacles, and the sediments are thin or rock is directly exposed around the pinnacles with irregular contour line. At the marginal part of the summit, rocks expose along the shoulder part and the upper part of the slope, there seems scarce sediments and wide exposure of rock.

3 - 3 - 2 Results of Sampling

At the MS11 seamount, dredging by the arm dredge (AD) and the chain bucket dredge (CB) were conducted for ten sampling points, sampling at three points by the LC, and the observation by the deep sea camera (FDC) along the one track line were, also, done in 1998 (Table 3-3-2-1). From these surveys, average thickness of the cobalt crust of 39mm,with average grade of Co of 0.69%, were obtained as the results.

In the survey of this year, drilling was conducted at the four sites from the MS11BMS01 to MS11BMS04 with drilling of 2 to 4 points (holes) per one site, totaling 11 drillings, and the sampling by the LC were carried out at the 9 points.

The location map of sampling, location map of drilling points, core correlation photographs and sampling results are shown as Figure 3-3-2-1, Figure 3-3-2-2, Figure 3-3-2-3 and Table 3-3-2-2, respectively. Photographs at the drilling points, photographs of cores, columnar profile of drilling core, seafloor photograph of LC and MC, columnar profile of LC and MC, are given in Appendixes 1 to 5.

In order to investigate the relation between MBES acoustic reflection intensity distribution and exposure of rocks, a detailed acoustic survey with cruising speed of 6 knot per hour, at the boundary area of dark and light tone of the MBES acoustic image

Table 3-3-2-1 Sampling Results of Previous Year in MS11 Seamount

No.	Sampling No.	Bottom Touch			Bottom Release			Topographic Division	Length /Amount (cm)/(kg)	Rock	Mn Crust
		Latitude	Longitude	Depth (m)	Latitude	Longitude	Depth (m)				
1	98SMS11LC01	10°53.958′ N	161°04.991′ E	4,353				W.lower slop	226 c m	calcareous clay	
2	98SMS11CB02	10°47.989′ N	161°22.620′ E	2,034	10°48.554′ N	161°23.390′ E	1,928	W.summit edge	17.88kg	basalt	cobbly crust, crust frag., nodule
3	98SMS11CB03	10°47.578′ N	161°22.248′ E	2,381	10°47.678′ N	161°22.713′ E	2,036	W.upper slop	0.26kg		crust fragment
4	98SMS11CB04	10°47.567′ N	161°29.945′ E	1,841	10°47.691′ N	161°31.148′ E	1,664	E.summit edge	0.10kg	pumice	
5	98SMS11CB05	10°56.283′ N	161°22.076′ E	1,818	10°56.283′ N	161°22.076′ E	1,698	W.summit edge	-		crust fragment
6	98SMS11AD06	10°54.178′ N	161°20.373′ E	2,374	10°54.280′ N	161°20.983′ E	2,109	W.upper slop	4.24kg	limestone, basalt	
7	98SMS11AD07	10°59.753′ N	161°21.744′ E	2,077	10°59.651′ N	161°22.131′ E	1,956	W.summit edge	2.28kg	basalt	crust fragment
8	98SMS11AD08	10°48.399′ N	161°31.955′ E	1,952	10°48.659′ N	161°32.889′ E	1,762	E.summit edge	2.64kg	basalt	crust fragment, crust
9	98SMS11AD09	10°53.415′ N	161°36.170′ E	2,515	10°53.099′ N	161°36.494′ E	2,447	E.upper slop	10.55kg	basalt,	crust,crust fragment
10	98SMS11AD10	11°05.200′ N	161°26.400′ E	2,667	11°05.200′ N	161°26.400′ E	2,468	N.middle slop	0.26kg	limestone, basalt	crust fragment, nodule
11	98SMS11LC11	10°57.253′ N	161°31.963′ E	1,670				E.summit edge	—		
12	98SMS11LC12	10°54.480′ N	161°32.865′ E	1,846				E.summit edge	—		
13	98SMS11AD13	10°44.755′ N	161°25.156′ E	1,921	10°45.023′ N	161°25.981′ E	1,928	S.summit edge	0.01kg		crust fragment

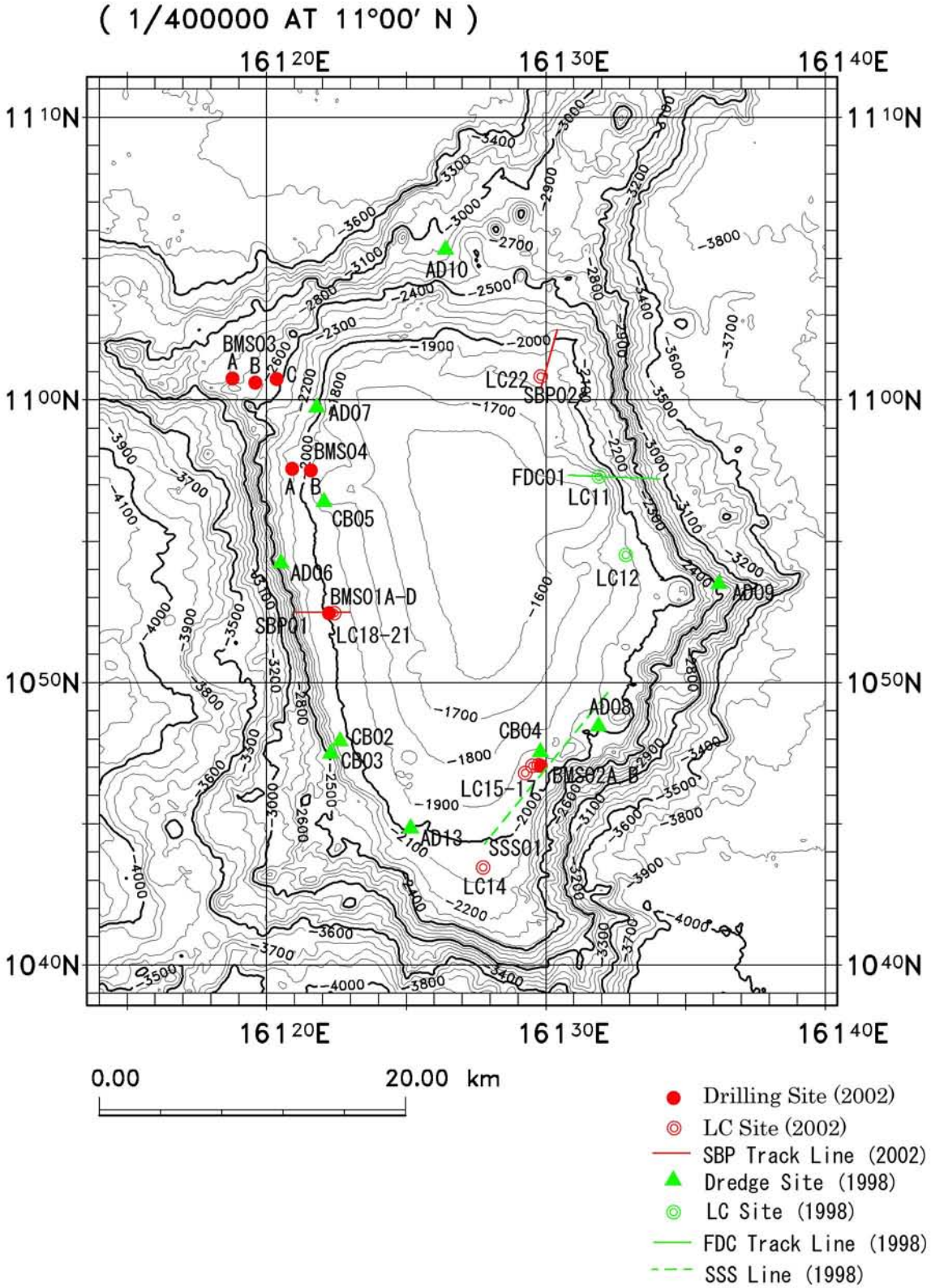


Figure 3-3-2-1 Sampling Location of MS11 Seamount

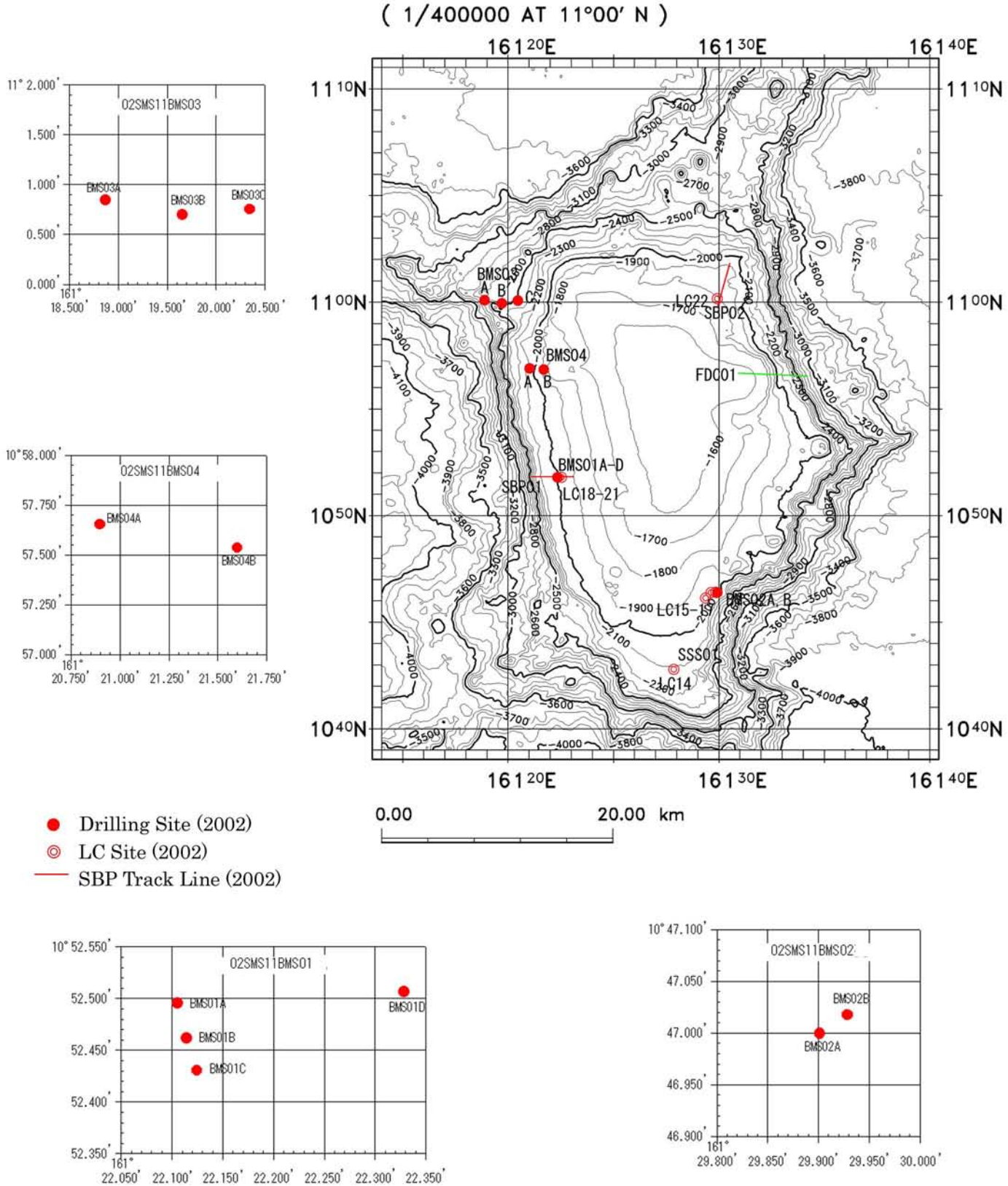


Figure 3-3-2-2 Location of Drilling Point in MS11 Seamount

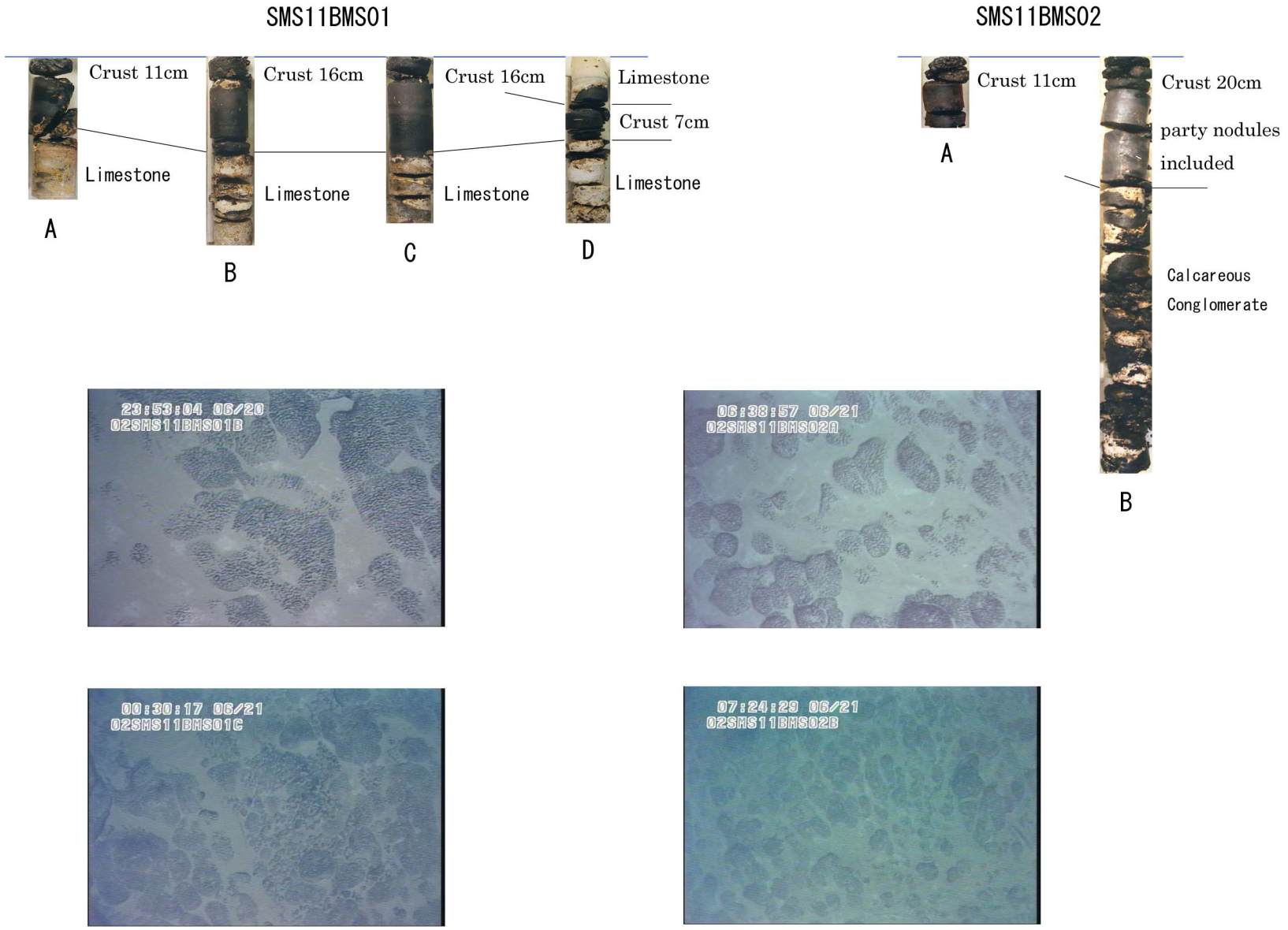


Figure 3-3-2-3 Correlation Core Photographs of MS11 Seamount (1)

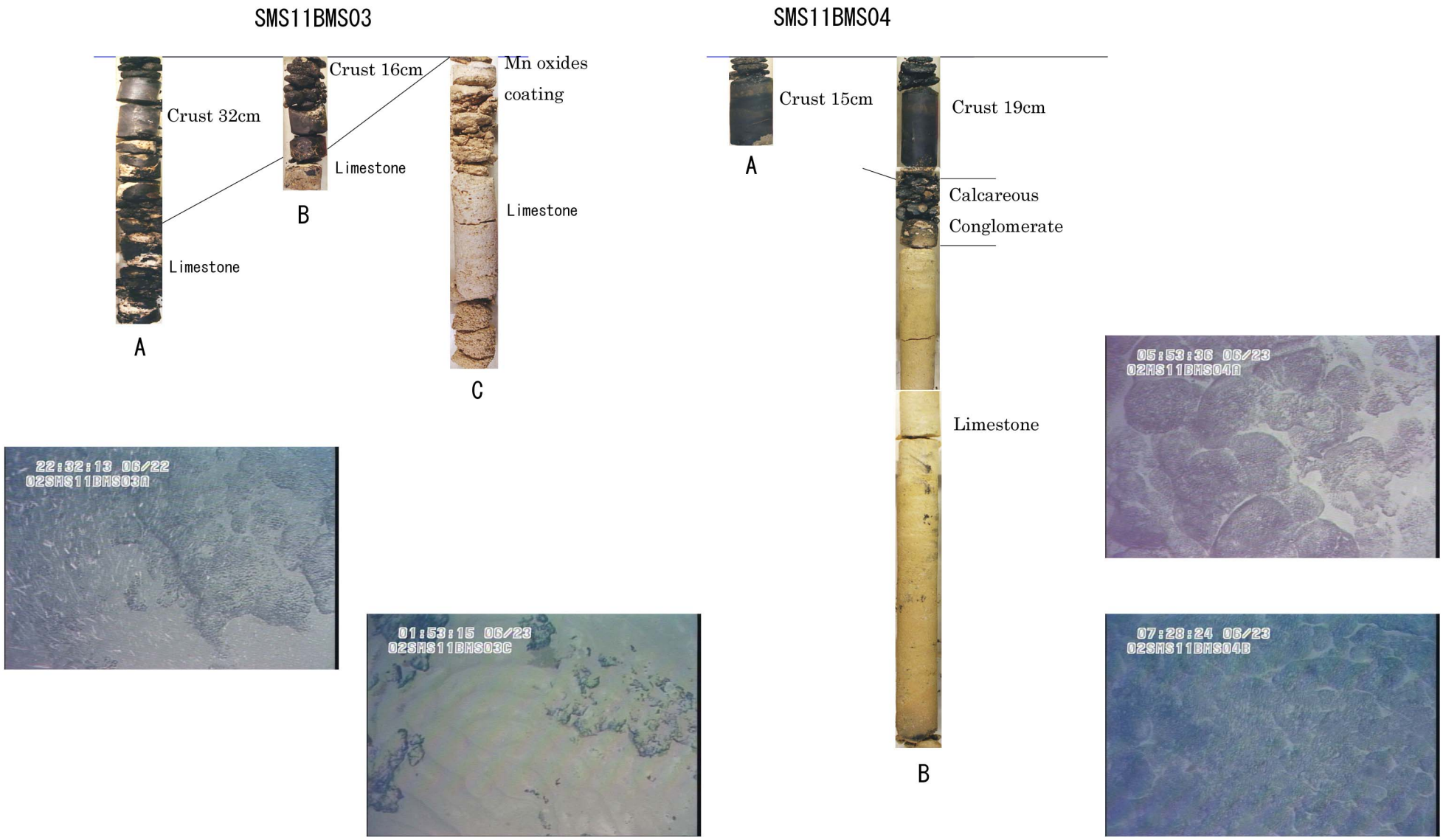


Figure 3-3-2-3 Correlation Core Photograhs of MS11 Seamount (2)

Table 3-3-2-2 Sampling Results of MS11 Seamouont

No.	Drill Site	Drill Point	Locations		Water Depth (m)	Core Bar-rel	Operation(cm)		Drilling Length (m)	Core Length (m)	Core Recovery (%)	Sediments (cm)	Rock Type (cm)
			Latitude	Longitude			start	end					
1	BMS01	02SMS11BMS01A	10°52.4953′ N	161°22.1058′ E	1,996	1	0	26	26	23	92	1	crust, nodule (14) 、limestone (9)
2		02SMS11BMS01B	10°52.4610′ N	161°22.1151′ E	1,990	1	0	34	34	32	94	0	crust (16) 、limestone (16)
3		02SMS11BMS01C	10°52.4295′ N	161°22.1254′ E	1,990	1	0	33	33	28	85	0	crust (16) 。limestone (12)
4		02SMS11BMS01D	10°52.5061′ N	161°22.3286′ E	1,971	1	0	176	176	28	61	130	limestone (8) 、crust (7) 、limestone (13)
5	BMS02	02SMS11BMS02A	10°46.9994′ N	161°29.9022′ E	1,983	1	0	20	20	11	58	1	crust (11)
6		02SMS11BMS02B	10°47.0166′ N	161°29.9290′ E	1,980	1	0	71	71	69	97	0	crust(20)、cal.conglo. (49)
7	BMS03	02SMS11BMS03A	11°00.8401′ N	161°18.8728′ E	2,750	1	0	49	49	47	96	0	crust (32) 、limestone (15)
8		02SMS11BMS03B	11°00.6941′ N	161°19.6624′ E	2,644	1	0	43	43	23	61	5	ﾉｼﾞｭｰﾙ (2) 、crust(16)、limestone (5)
9		02SMS11BMS03C	11°00.7486′ N	161°20.3522′ E	2,549	1	0	107	107	55	60	15	limestone(55)
10	BMS04	02SMS11BMS04A	10°57.6537′ N	161°20.9001′ E	2,081	1	0	32	32	15	47	0	crust (15)
11		02SMS11BMS04B	10°57.5342′ N	161°21.6022′ E	1,928	1	0	21	21	19	90	0	crust (19)
						2	21	178	157	104	66		cal.conglo. (10) 、limestone (94)
						Total			178	123	69		
12		02SMS11LC14	10°43.5012′ N	161°27.7591′ E	2,075					115			foraminiferal sand (115)
13		02SMS11LC15	10°46.7916′ N	161°29.3153′ E	1,954					0			
14		02SMS11LC16	10°46.9982′ N	161°29.5126′ E	1,977					50			foraminiferal sand (50)
15		02SMS11LC17	10°47.0995′ N	161°29.7078′ E	1,975					0			fragments of Mn oxides、bit deformed.
16		02SMS11LC18	10°52.4926′ N	161°22.3713′ E	1,968					0			fragments of limestone and Mn oxides
17		02SMS11LC19	10°52.5024′ N	161°22.3139′ E	1,974					90			foraminiferal sand(90)、bit deformed
18		02SMS11LC20	10°52.5057′ N	161°22.2202′ E	1,977					3			cobble crust (3) 、bit deformed.
19		02SMS11LC21	10°52.5071′ N	161°22.2583′ E	1,977					0			fragments of Mn oxides、Mn deformed
20		02SMS11LC22	11°00.8291′ N	161°29.8460′ E	1,844					95			foraminiferal sand (95)

cal.conglo.: calcareous conglomerate

at the west and the north of the summit area of the MS11 seamount was conducted. The MBES acoustic intensity image is shown with the seafloor photographs of sample points in Figure 3-3-2-4 (SBP01 line) and Figure 3-3-2-5 (SBP02 line).

Descriptions of samples together with circumstances of seafloor at the sampling point are given below

3 - 3 - 2 - 1 02SMS11BMS01 Site

Drilling Site: At the western part of the summit of the MS11 seamount, dark zone of the MBES acoustic image with 2km width exists between the water depths of 1,900m to 2,100m, suggesting exposure of rocks. The drilling, BMS01, was done to understand the distribution of cobalt crust at the dark tone area. Preceding the drilling, acoustic survey was conducted from the flat summit to the slope area (SBP01), and 4 points of LC sampling, LC18 to LC21, were done on the basis of the acoustic survey result. Three holes, A (core length of 26cm), B (34cm), and C (33cm), were drilled at the dark tone area suggesting exposure of rocks, with drilling point apart each other about 50m along NNW-SSE direction. The drilling point D (drilling length of 176cm) is positioned about 300m apart from the three points toward west, or close to the summit, and adjacent to the LC19 point, and it is located on the boundary of dark and light tone of the MBES acoustic image. This was aimed to confirm the development of cobalt crust beneath the top sediments.

Circumstances of seafloor: The seafloor at the point A, B, and C, is similar, and the exposed crust surface shows swelled, globular to ellipsoidal shape surface with diameter or long axis of 20cm to 50cm, but its general appearance is platy crust with comparatively flat surface as a whole. The rate of exposure is 30% to 40% around the point A and B, and high, 50% to 80% around the point C. The drilling point A is positioned on the thin sediments between gently swelled exposed surfaces of the cobalt crust. The point B and C is directly on the flat platy cobalt crust. Around the D point, the exposure of the cobalt crust is not observed, and the drilling was done on the sediments showing ripple mark.

Cobalt crust: Thickness of the crust at the point, A, B, and C is, 95mm, 160mm, and 160mm, respectively, and at the point A nodule occurs between the crust and the bedrock. It shows two-layer structure at A and B , and three-layer structure at the point C. At the drilling point D, the top part is covered with

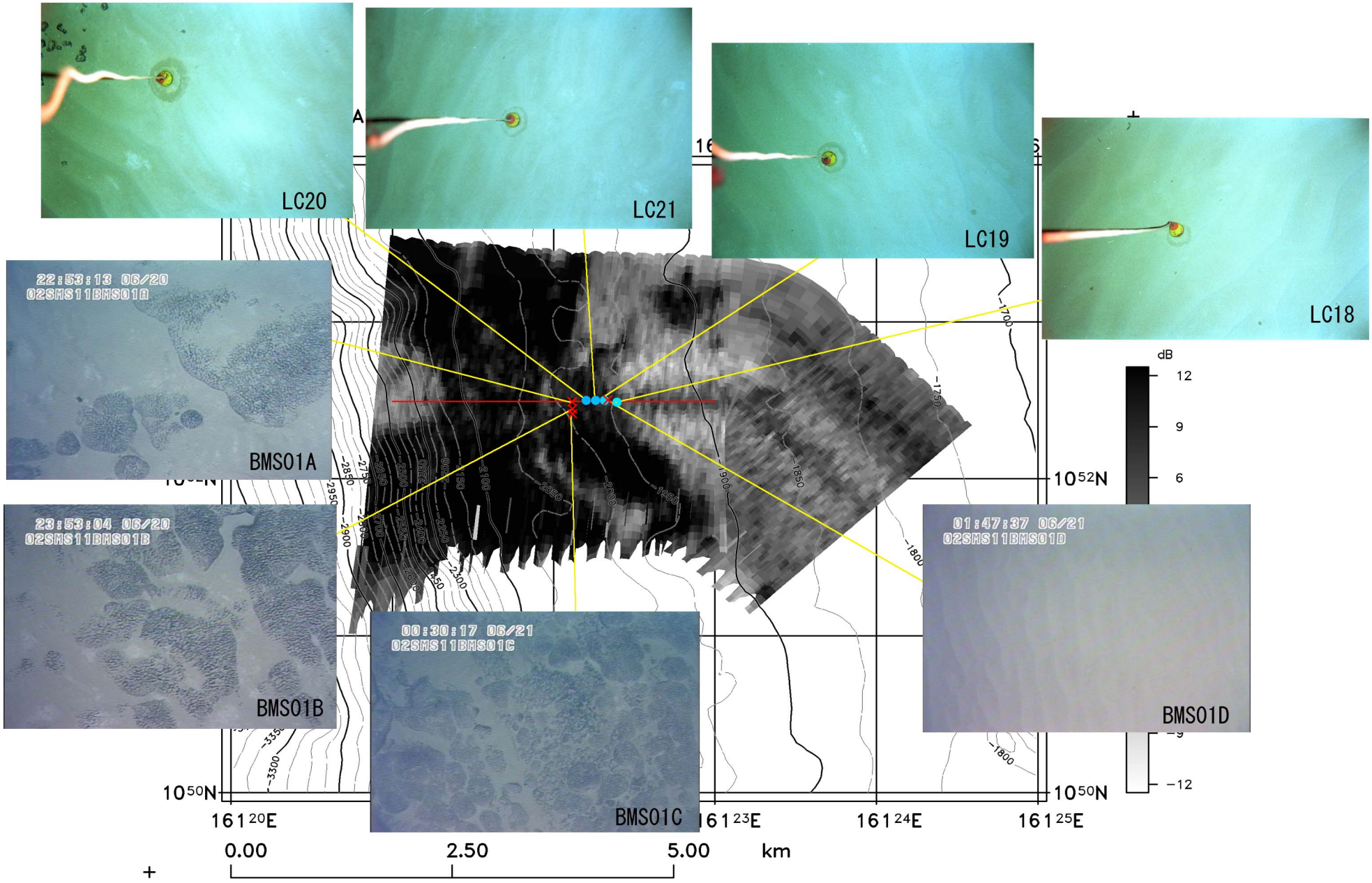


Figure 3-3-2-4 Acoustic Reflection Map of Track Line SBP01

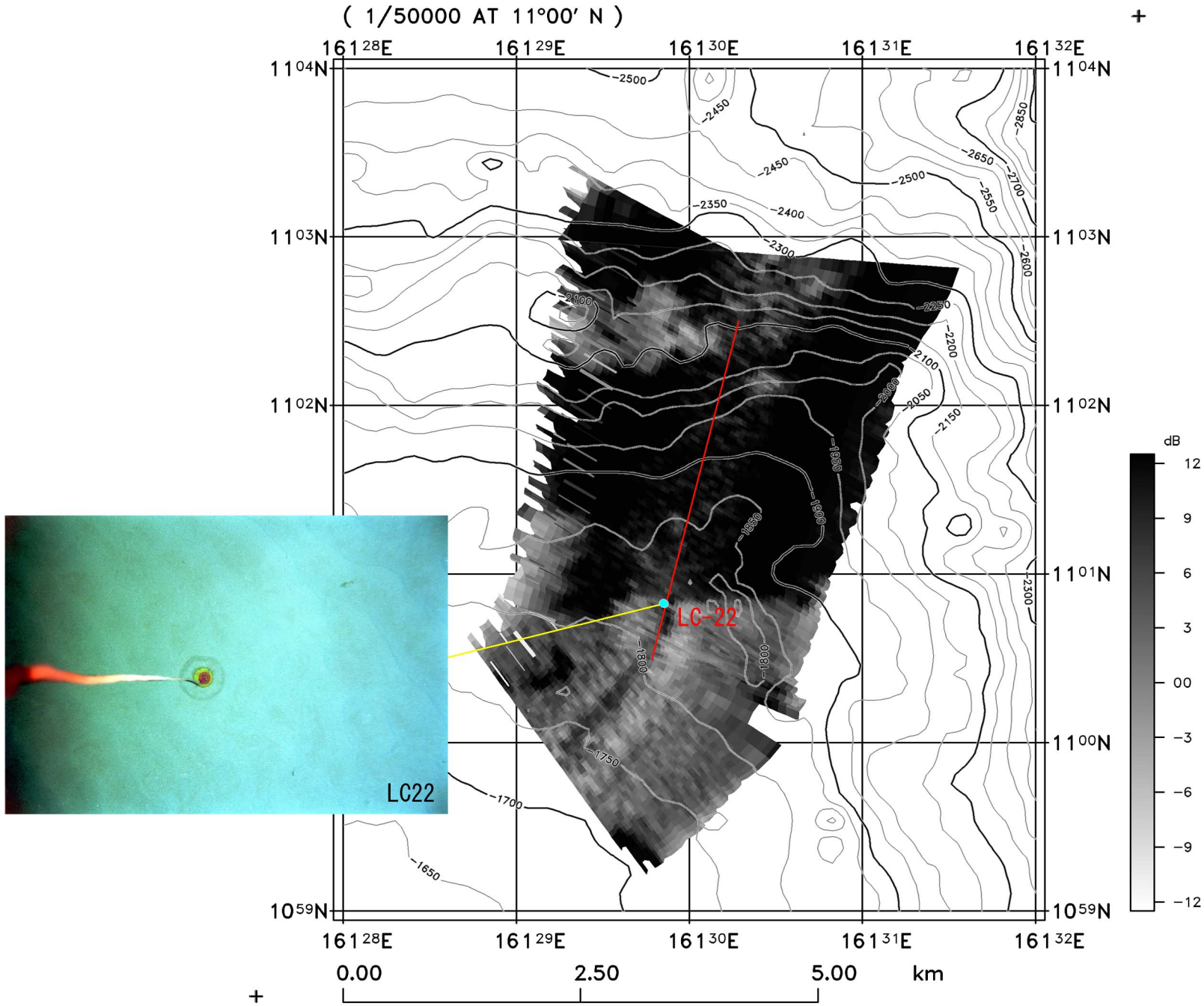


Figure 3-3-2-5 Acoustic Reflection Map of Track Line SBP02

unconsolidated sediments of 130cm thickness, and from upper to the lower, 8 cm thick limestone, 70mm thick three-layered crust, and limestone again. Accordingly, at the point D, it is thought that the crust had been formed at the top of the lower limestone and the cobalt crust had been overlain by limestone of later stage again. The average crust thickness at this site is 121mm.

Rock sample: Limestone was collected at four points, A, B, C, and D. Limestone shows pale brown to pale yellowish white color, and contains glassy volcanic pebbles of size of 2mm to 20mm and cobble of limestone. The limestone of the upper part of the crust at the point D shows pale brownish white, pelagic limestone with foraminiferal fossil.

3 – 3 – 2 – 2 02SMS11BMS02 Site

Drilling Site: Rather wide distribution of dark tone area in the MBES acoustic image is observed at the eastern margin of summit in south of the seamount. The drilling, BMS02, was done to grasp the distribution of cobalt crust at the south of the summit. Preceding the drilling, LC15 to LC17 sampling were conducted at the points included in the light tone to dark tone area of the acoustic image. The BMS02 point is located near the LC 17 point where distribution of the cobalt crust was confirmed. Two drillings were conducted at this site, point A (drilling length of 20cm) and the point B (71cm) located 60m northeast of the point A.

Circumstances of seafloor: The drilling points A and B show similar seafloor, and the exposed crust surface shows swelled, globular to ellipsoidal shape surface with diameter or long axis of 20cm to 50cm like aggregates of boulder. The rate of exposure is 60% around the point A, little higher than at the point B of 40%. The drilling point A is positioned on the periphery of the swelled, globular shape crust, and the surface is inclined about 10 degrees. The position of the point B is on the junction of three globular swelled crusts.

Cobalt crust: At the point A, two-layered crust of thickness of 110mm without bedrock was obtained, and at the point B, two-layered crust similar to the point A. The thickness of the crust at point B is 150mm. Under the crust, there occurs cobble like crust of 35mm thick. The lower part of this crust is calcareous conglomerate containing nodules of diameter of 5 cm to 8cm with manganese

oxides thickness of 15mm to 30mm. The thickness of the cobalt crust at this site is, from averaging the point A and B, 130mm.

Rock sample: Bedrock was not obtained at the point A. At the point B calcareous conglomerate with white limestone matrix was obtained. It contains nodules of diameter of 5cm to 8cm with glassy basalt as nucleus.

3-3-2-3 02SMS11BMS03 Site

Drilling Site: The upper part of the slope at the northeast is included in dark tone area and the slope angle is comparatively gentle. The drilling site, BMS03, was selected with different depths to grasp the distribution of cobalt crust on the slope. Three drillings, A (drilling length of 49cm), B (43cm), and C (107cm) were conducted at the site from west to east direction taking 1.0km to 1.5km distance, and the depth of water has about 100m difference between each point, 2,750m, 2,644m, and 2549m, respectively.

Circumstances of seafloor: Around the drilling point A, the seafloor consists of the comparatively flat platy crust, but parts of the exposed surface shows globular swelled surface of diameter of about 50cm, as if they were aggregates of boulder, and the exposure rate of the surface is 30% to 90%. The drilling point A is positioned at the periphery of the platy crust, and the surface is inclined about 10 degrees. Surface around the point B is poor in crust exposure with exposure rate of about 10%, and the exposed surface shows aggregates of boulder-like globular swelled surface of diameter of 20cm to 50cm. The drilling point is on the unconsolidated sediments surrounded by crust exposure. The drilling point C shows comparatively flat crust surface covered with unconsolidated sediments. The sediment cover pattern is irregular, and the crust exposure rate is 10%. The point C is positioned on the sediments among the exposure of cobalt crust.

Cobalt crust: The sample obtained at the point A is brecciated into 1cm to 5cm angular fragments and thus detail is not evident, but taking into account of the core length, the thickness of the crust seems to be 320mm. At the point B, the succession begins from nodules of diameter of 1cm to 2 cm and the below is constituted by three-layered crust with a thickness of 160mm. At the point C, the surface is covered with sediments of thickness of 15cm, and the below

consists of limestone coated by manganese oxides on surface and lacks crust. The detail of the crust of the point A is not clear and thick crust may be resulted to the drilling position at the marginal portion of the exposed crust. The point C is covered by sediments of 15cm thick, and only coating of manganese oxides are observed. The average thickness of the cobalt crust of three drilling points becomes 160mm. It seems probable that the distribution of thick cobalt crust of 160mm or so exposed at the upper slope of the northeast of the seamount.

Rock sample: Limestone was obtained at the points, A, B, and C. The sample at the point A is limestone rarely includes white manganese oxides grain. Limestone at the point B and C shows pale brownish white color and contains limestone fragments several mms across, grains of manganese oxides, and shells of foraminifer.

3 - 3 - 2 - 4 02SMS11BMS04 Site

Drilling Site: At the periphery of the northeastern part of the summit, the dark tone area in the acoustic image is observed at water depth of about 2,000m. The drilling of BMS04 site was conducted to grasp the development of cobalt crust at the northeast periphery of the summit. Two drillings at the point A (drilling length of 32cm) and B (178cm) were conducted at the site. The depth of water at the point A is 2,081m and the point B, apart about 1.5km to the ESE direction from B, is 1,928m. The drilling at the point B was aimed to obtain the information of bedrock.

Circumstances of seafloor: The seafloor around the drilling point A shows aggregates of boulder-like swelled surface of globular to ellipsoidal shape with diameter or long axis of 10cm to 50cm and the exposure rate is 50%. The drilling point is positioned on the surface of comparatively flat, platy crust, among the globular shape crust surface. The seafloor at the point B shows comparatively flat platy crust surface with swelled, globular to ellipsoidal shape crust surface of diameter or long axis of 20cm to 50 cm. The swelled portions align directionally. The drilling point B is positioned on the comparatively flat platy crust.

Cobalt-rich crust: At the point A, Bedrock sample was not obtained and only cobalt crust sample was collected. The thickness of the crust is 130mm having two-layer structure, and the lowest part of the crust contains nodule of thickness of 20mm. The crust at the point B is similar to that of A, having two-layer structure, containing nodule of 20mm thick at the lower part. The difference of water depth is 150m between A and B, but the occurrence of the crust resembles, and about 145mm thick crust, as of the average thickness of both samples, is assumed to be develops at the periphery of the northeast of the summit.

Rock sample: Bedrock was no obtained at the point A, but limestone collected at point B. It is yellowish brown, porous limestone, including shells of foraminifer and fine grain manganese oxides.

3 - 3 - 2 - 5 Results of Sampling by LC

LC sampling was conducted at 9 points in the four sites of the summit area, aiming to understand the distribution of cobalt crust and the characteristics of sediments.

(1) South of the summit

The site is included in the light tone area in the acoustic image, and is assumed the area to be covered by thick sediments. The LC14 sampling was done to obtain the sediments. Seafloor photograph shows a distribution of sediments over the whole seafloor with ripple mark. Brown colored coarse grain foraminiferal sand of 115cm thick was obtained at this point.

(2) Southeastern part of the summit

In this site, dark tone area in the acoustic image at the margin of the summit makes clear boundary with the light tone area at the summit area. Three LC samplings, each of which apart 500m, were conducted to confirm the relation of acoustic intensity and the exposure of cobalt crust. The point LC15, LC16, and LC 17 are positioned, in the light tone area, the boundary of light and dark tone, and dark tone area, respectively. In the seafloor photographs, unconsolidated sediments with ripple mark cover the surface at the point LC15 and LC16, and comparatively flat platy crust crops out with exposure rate of about30% at the LC17 point. No sample was obtained at the LC15 point, but there was neither the deformation nor damage on the tip of the bit, and foraminiferal sands were likely to be lost on the occasion of raising

up the equipment. Pale brown a little coarser foraminiferal sand of thickness of 50cm was obtained at LC16, and crushed crust fragments at LC17.

(3) Western part of the summit

At the margin of the western part of the summit, a detailed acoustic survey was conducted to confirm the relation with acoustic data and exposure of crust, and LC sampling was conducted at four points along the acoustic survey line. The position aligns from the summit side to the marginal direction, the points LC18, LC19, LC21, and LC20 and they correspond to the area of intermediate tone, boundary of intermediate tone and dark tone, dark tone, and dark tone, respectively. Seafloor photographs show, top sediments with ripple mark cover the area around the points LC18, LC19, and LC 21. The point LC 20, closest point to the slope, shows distribution of nodules over the top sediments with ripple mark. At the point LC18, which shows intermediate tone, limestone and small fragments of manganese oxides were collected. It is assumed that coarse foraminiferal sand was washed away while raising up the LC equipment because there was no deformation on the tip of the bit. At the point LC19, 90cm thick foraminiferal sand was collected. Close to the point LC19, the BMS01D was conducted, and limestone and crust were obtained covered by sediments of 130cm thick. Fragments of crust were obtained at the point LC21 and LC20, and the LC bit was damaged. Seafloor photographs show that both points are covered with sediments but it is thin, perhaps less than several centimeters, and there develop crust beneath the sediments.

(4) Northeast of the summit

At the margin of the summit of the northeast of the seamount, there develop comparatively wide dark tone areas with 3km width from the water depth of 1,800m to 2,000m. A detailed acoustic survey and sampling by BMS and LC was planed to confirm the relation of acoustic intensity distribution and exposure of crust. However, only one LC sampling was conducted due to the bad weather. The LC22 sampling was carried out at the border of light and dark tone of the acoustic image. The seafloor photograph showed distribution of sediments over the whole surface area and a little coarse, foraminiferal sand of 95cm thick was obtained.

3 - 3 - 3 Geology

Rock samples and type of cobalt crust samples obtained by the survey of this year are shown together with results of previous year in Figure 3-3-3-1. For characteristic rock samples, thin section observation and fossil test were conducted and for unconsolidated sediments fossil identification was conducted

3 - 3 - 3 - 1 Outline of Geology

Adding the information of previous year, samples obtained at the MS11 seamount are basalt, limestone and phosphorite, calcareous conglomerate, and foraminiferal sand together with cobalt crust.

Almost all of rock samples at the MS11 seamount are basalt and conglomerates. Basalt is collected at the summit and the slope of the margin of the summit by dredging. Limestone samples are obtained at the comparatively flat margin of the summit and at the terrace-like topography. Other than these, limited numbers of phosphorite and pumice samples are obtained.

The distribution and characteristics of these rocks are as follows.

Basalt: It seems to show wide distribution at the top of the seamount and the slope of the margin of the summit. Almost all of samples obtained by the dredging survey of the previous year are basalt. It is, brownish gray to dark gray in color, fine, compact rock. Groundmass is vitric and it includes small plagioclase and pyroxene as phenocryst. Basalts observed in the calcareous conglomerate sample of BMS02B and BMS04B points are brown, fine, vitric basalts.

Limestone: At BMS02 point, calcareous conglomerate was collected, but other than that, limestone was collected from all of the holes, and thus the limestone seem to dominate in the comparatively flat area of the summit and terrace-like area along the middle part of slope where BMS03 is located. They are pelagic limestone showing white to pale brown color and containing shells of foraminifer and fine particles of manganese oxides. At BMS04B point where 1.78m deep drilling was conducted to grasp the bedrock information, limestone with core length of more than 1m was collected, suggesting the development of comparatively thick limestone deposition.

Calcareous conglomerate: Calcareous conglomerate were obtained at BMS02B and BMS04B points. Matrix is white limestone including pebbles of basalt covered with manganese oxides. It is thought that the precipitation of manganese oxides had started

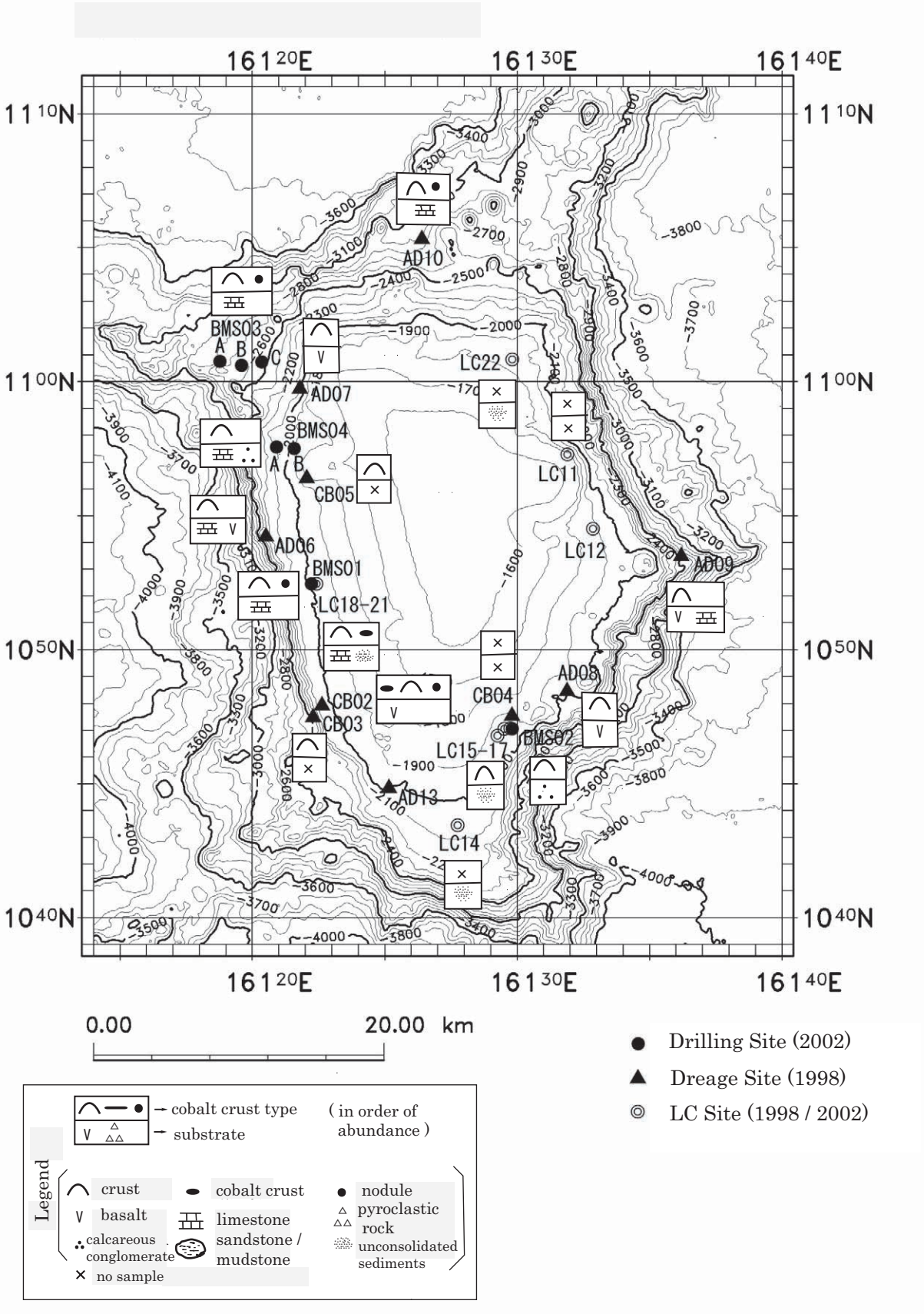


Figure 3-3-3-1 Distributions of Rock and Cobalt Crust in MS11 Seamount

before or in parallel with the deposition of calcareous matrix.

With above evidence, the geologic history at the MS11 seamount is as follow.

After the formation of basalt to form the basal part of the seamount, the seamount had subsided rather rapidly, and had been covered with pelagic limestone. Basalt is observed along the slope area but the flat area of the summit is covered with comparatively thick limestone. There are facts that limestone contains fine particles of manganese oxides, calcareous conglomerate includes basalt pebbles covered with manganese oxides, and that the cobalt crust covers the limestone and calcareous conglomerate. From these facts the formation of cobalt crust is assumed to have been started before the formation of calcareous rocks, and the precipitation had continued after that.

3 - 3 - 3 - 2 Thin Section Observation

For the purpose of clarifying the characteristics of typical rock samples and determine the rock type of unknown rock due to alteration, microscopic observation was conducted. The description of the microscopic observation and the results are shown in Table3-3-3-1 and Appendix 6, and photographs of petrographic microscope are given in Appendix 7.

On the MS11 seamount, petrographic observation was made for two limestone samples: the limestone sample obtained at the margin of the western part of the seamount (BMS01BTS01) and on the terrace of middle part of slope (BMS03BTS01). Both samples contain exotic rock fragments.

The BMS01BTS01 is calcareous, clastic conglomeratic sandstone whose matrix is stuffed with foraminiferal limestone. It contains abundant basaltic scoria with plagioclase and olivine basalt fragments. The summit area of the seamount shows dome like upheaval, and the BMS01 site is located at the margin of the summit, and thus the rock seems to have been formed by the supply of clastic materials from the summit area.

The BMS03BTS01 consists of matrix composed of foraminiferal limestone and basaltic scoria with mosaic shaped boundary, and limestone adjacent to basaltic scoria is receiving hydrothermal alteration. From this point, this rock sample has possibility to be peperite, formed by the intrusion of basaltic lava into calcareous ooze.

Table 3-3-3-1 Microscopic Observations for Rock Thin Section of MS11 Seamount

Sample No.	Occurrence	Rock Type	Microscopic Observations
02SMS11BMS01B TS01 collected at 28-32cm	limestone covered by crust.	white to gray , compact calcareous matrix with brown granules	**calcareous sandstone** : detrital fragments consists of subangular to subround basaltic scoria, plagioclase and olivine basalt, matrix mainly consists of foraminifera fossils.
02SMS11BMS03B TS01 collected at 23-28cm	bedrock of crust	grayish white to pale brown, porous calcareous matrix with black rock fragments.	**basaltic hyaloclastite-peperite** : detrital fragment consists of basaltic scoria, matrix consists of fine calcite and foraminifera, mosaic boundary between detrital fragments and matrix suggests basaltic lava had intruded into calcareous ooze.

3 - 3 - 3 - 3 Fossil Test

The test was done to make clear the deposition age of sedimentation and sedimentary environment. The results are shown in Table3-3-3-2 and Table 3-3-3-3. The list of yielded fossils and photographs of typical fossils are shown in Appendix 10.

(1) Sediments

Fossil test was made on three samples from LC 14, and two samples from the LC19, five samples in total. The LC14 is located at the south of the summit where is correspond to light tone area in the acoustic image. The obtained sample is foraminiferal sand of core length of 115cm, and fossils were tested for three samples, 10cm to 15cm depth (FS01), 55cm to 60cm (FS02), and 110cm to 115cm (FS03). The LC19 point is positioned west of the summit and located on the boundary of middle tone and dark tone in the acoustic image. The drilling point BMS01D, adjacent to the LC19 point, shows 130cm thick sediments and limestone and crust beneath it. Foraminiferal sand of core length of 90cm was obtained at LC19, and two samples, 15cm to 20cm(FS01) and 70cm to 75cm (FS02) ware tested.

This five samples show that the geologic age of the deposits assumed by nanno plankton is younger than that given by foraminifer. One possibility is that the foraminifer bearing sand had been derived as the result of rework. Actually, in the samples of the FS01 and the FS02 of the LC14, Pliocene fauna are mixed in early Pleistocene fauna. The sample tested this time does not include crushed shell or altered color shell, and thus it is unlikely that foraminifers had selectively been re-deposited by constant slow flow like bottom current.

The LC14 is located at the margin of the seamount, and there is a possibility that the allochthonous sediments had been transported on the occasion of collapse of the slope and it had re-deposited there. The age of the re-deposition would be middle Pleistocene (FS03: 0.41 Ma to 0.51 Ma) or late Pleistocene (FS01: 0 to 0.16 Ma, FS02: 0.16 to 0.25Ma). The age assumption made by foraminifer and nanno plankton by using the sample of LC19 differs quite an extent, but the assemblage of fossil fauna to suggest the rework has not been evident. The LC19 is located at the margin of the seamount as same as the LC14, the sample is assumed to be deposited at late Pleistocene (0 to 0.16 Ma).

From assemblage of foraminiferal fauna, the environment of deposition is assumed to be sub-tropical geographic province. Benthonic foraminifers are rarely observed, for this reason, the assumption of paleo-depth can not be decided, it would be from 800m to 2,500m. The sedimentation rate is calculated to be 1.57mm/1,000 years to

Table 3-3-3-2 Results of Fossil Test of Sediments of MS11 Seamount

Site	Depth (m)	Sample No.	Sampling Depth (cm)	Type of Sample	Age Foraminifera	Age Nannofossil	Foraminifera	Nannofossil
02SMS11 LC14	2,075	FS01	10-15	foraminiferal Sand	early Pleistocene (1.6－2.0Ma)	late Pleistocene (0－0.16Ma)	FS01 includes *Globigerinoides ruber* (pink) and *Globorotalia truncatulinoides,* and geological age is Pleistocene. Pliocene fossils such as *Globigerinoides obliquus* and *Globoquadrina altispira* are included, however they are considered to be products of resedimentation. Abundant occurrence of *Globigerinoides fistulosus* suggests geological age to be early Pleistocene (1.6～2.0Ma). FS02 and FS03 include *G. truncatulinoides* and *G. fistulosus*, corresponding to geological age of early Pleistocene (1.6～2.0Ma). FS03 has *Globigerinoides extremus* corresponding to geological age of 1.77～2.0Ma.	Occurrences of *Emiliania huxleyi* and no existence of *Helicosphaera inversa* suggest fossil zone of NN21 corresponding to 0-0.16 Ma, younger than Standard Horizon 1.
		FS02	55-60	foraminiferal Sand	early Pleistocene (1.6－2.0Ma)	late Pleistocene (0.16－0.25Ma)		Occurrences of *Emiliania huxleyi* and *Helicosphaera inversa* suggest fossil zone of NN21. From *Helicosphaera inversa* geological age corresponds to 0.16-0.25Ma,
		FS03	110-115	foraminiferal Sand	early Pleistocene (1.6－2.0Ma)	middle Pleistocene (0.41－0.51Ma)		Occurrences of *G. parallela* , *Pseudoemiliania lacunosa* , and *H. inversa* suggest geological age of 0.41-0.51, corresponding to Standard Horizon of 3-4, upper part of fossil zone NN19.
02SMS11 LC19	1,974	FS01	15-20	foraminiferal Sand	early Pleistocene (1.6－1.77Ma)	late Pleistocene (0－0.16Ma)	FS01 and FS02 include *G. truncatulinoides* and *G. fistulosus* of Pleistocene. *G. obliquus* in FS02 suggests FS02 is older than FS01. FS01 and FS02 correspond to geological age of 1.6～1.77Ma and 1.77～2.0Ma.	Occurrence of *Emiliania huxleyi* and no existence of *Helicosphaera inversa* suggest geological age of 0-0.16 Ma, corresponding to fossil zone of NN21.
		FS02	70-75	foraminiferal Sand	early Pleistocene － late Pliocene (1.77－2.0Ma)	late Pleistocene (0－0.16Ma)		Occurrence of *Emiliania huxleyi* and no existence of *Helicosphaera inversa* suggest geological age of 0-0.16 Ma, corresponding to fossil zone of NN21.

Table 3-3-3-3 Results of Fossil Test of Rocks of MS11 Seamount 1/2

Site	Depth (m)	Sample No.	Sampling Depth (cm)	Topographic Division	Type of Sample	Rock Name	Remarks	Geological Age	
								neritic	pelagic
02SMS11 BMS01D	1,971	FR01	130-138	W. Summit Edge	limestone covered by sediments of 130cm thick, Mn crust was not observed on the surface.	foraminiferal packstone / grainstone	Foramineferas such as *Acarinina, Truncorotaloides, Morozovella* were found, geological age is late Eocene（P15～P17）.	—	late Eocene
		FR02	145-148	W. Summit Edge	limestone covered by Mn crust, includes vitric volcanic rock.	intraclast rudstone	Reefal limestone, texture of cements suggests diagenesis by terrestrial water, fossils such as *mullusca, Echinoidea, Bryozoa, Solenopora are include*, micrite envelope is observed.	Cretaceous	—
02SMS11 BMS03A	2,750	FR01	32-47	NW. Middle Slop	limestone covered by Mn crust.	bioclastic grainstone	Reefal limestone, texture of cements suggests diagenesis by terrestrial water, fossils such as *mullusca, Echinoidea, Bryozoa, pachyodonts* are found, *Pachyodonts* suggests geological age to be Cretaceous.	Cretaceous	—
02SMS11 BMS03C	2,549	FR01	45-58	NW. Middle Slop	porous limestone covered by 15cm thick sediments, Mn crust was not observed on the surface.	bioclastic packstone / grainstone	Reefal limestone, texture of cements suggests diagenesis by terrestrial water, pelagic limestone fills void of reefal limestone, fossils such as *Mollusca*, *Echinoidea, miliolinid a* re found, *Hedbergella, C*retaceous foraminifera is observed.	Cretaceous	Cretaceous?

Table 3-3-3-3 Results of Fossil Test of Rocks of MS11 Seamount 2/2

Site	Depth (m)	Sample No.	Sampling Depth (cm)	Topographic Division	Type of Sample	Rock Name	Remarks	Geological Age	
								neritic	pelagic
02SMS11 BMS03C	2,549	FR02	58-65	NW. Middle Slop	sandy limestone, occurs beneath FR01.	bioclastic rudstone	Reefal limestone, texture of cements suggests diagenesis by terrestrial water, fossils such as *Mollusca*, *Echinoidea, miliolinid, Amphistegina a* re found, *Hedbergella, C*retaceous foraminifera is observed.	Cretaceous	Cretaceous?
02SMS11 BMS04B	1,928	FR01	31-36	NW. Summit Edge	porous limestone covered by Mn crust.	bioclastic grainstone	Reefal limestone, texture of cements suggests diagenesis by terrestrial water, fossils such as *Mollusca*, *Echinoidea, miliolinid a* re found, Occurrence of *Subbotina* suggests geological age of Paleogene.	Cretaceous	Paleogene？
		FR02	101-121	NW. Summit Edge	limestone similar to FR01	bioclastic grainstone	Reefal limestone, texture of cements suggests diagenesis by terrestrial water, benthic foraminifera, *Biserial,* is found, occurrence of *Subbotina* suggest geological age of Paleogene.	Cretaceous	Paleogene？

1.80mm/1,000 years at LC14 and 3.43mm/1,000 years at LC19. They are slow as the sedimentation rate of calcareous sediments.

(2) Fossil test of rock sample

Tested samples are seven samples of, BMS01DFR01 and FR02 sampled at the margin of the west of the summit, BMS03AFR01, BMS03CFR01, and FR02, at the middle slope of northwest of the seamount, and BMS04BFR01 and FR02 samples, which were sampled near the margin of the summit and adjacent to the BMS03 site, with the water depth of about 600m shallower than BMS03 site. At the BMS01D sites, there develop top sediments of thickness of 130cm, and two limestone layers develop beneath it, and the crust of thickness of 70mm is intercalated between the upper limestone (FR01) and lower limestone (FR02). The drilling points, BMS03A and BMS03C were located at the middle slope with the water depth of deeper than 2,500m. At the BMS03A, there is no top sediments and the limestone is directly exposed covered by thick crust. The latter, the BMS03C point, is covered by 15cm thick sediments and the surface of the limestone is coated by manganese oxides. The BMS03CFR01 and FR02 are obtained at the close point of the drill core, and the former is porous limestone and the latter is the limestone containing abundant clastic fragments. At the drilling point BMS04B, there exists cobalt crust of thickness of 160mm, and the cobalt crust is succeeded by limestone. Two limestone samples FR01 and FR02 were sampled with 70cm distance. The detailed result of the fossil test is shown in Appendix 10.

The BMS01DFR01 sample is foraminiferal limestone but other six samples are reef limestone. From the fossil test, the reef limestone is assumed that it was deposited in Cretaceous Period, and foraminiferal limestone was in late Oligocene. The two samples of the BMS04B sample have possibility to be deposited in Paleogene time. All of reef limestone receives diagenesis by terrestrial water.

After the fossil test, the geologic history of the MS11 seamount is thought as follow.

In accordance with the uplift of the seamount, a reef had been formed at the margin of the seamount between the site of BMS01 and BMS03 (present water depth of 1,971m to 2,750m) and deposition of limestone had been started (The limestone of the BMS04B site has a possibility of deposition in Paleogene). After the site BMS03 (present water depth of 2,750m) had been exposed over the sea surface, the seamount had submerged and in late Eocene, the BMS01site was submerged to the depth to allow the deposition of foraminiferal limestone. There exists the cobalt crust between the two samples, BMS01DFR01 and FR02, the age of the formation of this cobalt crust is thought between Paleocene and Eocene. Also at the BMS03A point and the BMS04B point, the

layer of limestone are observed to be covered by the crust, therefore the formation of the cobalt crust was started after Cretaceous Era. According to Watkins et al. (1995), the main stage of the formation of cobalt crust in this area and the vicinity is Eocene to Oligocene.

3 - 3 -4 Occurrence of Cobalt Crust

At the MS11 seamount, as the survey of 1998, sampling at the thirteen points (AD: 6 points, CB: 4 points, LC: 3points) was conducted and cobalt crust sample was obtained from eight points. On the basis of this survey, average thickness of the cobalt crust of 36mm and average grade 0.69% were obtained.

In the survey of this year, four sites from the area of gentle slope with expected exposure of cobalt crust were selected, taking into account of easier exploitation in the future, and drilling survey and the LC sampling were conducted. The purpose of the survey is to understand nature of cobalt crust distribution in the summit area and in different water depths and to clarify horizontal continuity and occurrences under sediment coverage.

3 - 3 - 4 - 1 Distribution

(1) Thickness of cobalt crust

The results of the sampling of cobalt crust of this year and the survey of 1998 are given in Table 3-3-4-1 and Table 3-3-4-2, and the distribution of the cobalt crust is shown in Figure 3-3-4-1. The relations of thickness and water depth, and thickness of cobalt crust and sediments are given in Figure 3-3-4-2 and in Figure 3-3-4-3.

The survey of 1988 was conducted centering the margin of the summit area including the upper to middle slope and obtained samples of crust, cobble crust and small amount of nodules. Average thickness of cobalt crust at the each sampling points was, excluding nodules, 2mm to 100mm, and when the result of two points (AD10, AD13), where the amount of samples was small, were excluded, average thickness at six points is calculated to be 36mm. The average thickness at the summit shallower than the water depth of 2,100m was not so uniform, 2mm to 49mm and no thick sample of more than 50mm thick was obtained. On the other hand, along the slope area deeper than the water depth of 2,100m, samples with average thickness of 100mm was obtained at the AD09 point. Other than this point, average thickness was 5mm to 10mm.

In the survey of this year, a total of 11 holes, 8 points at 3 sites at the summit with water depth shallower than 2,100m, and 3 points at 1 site at the middle slope, were

Table 3-3-4-1 Cobalt Crust Samples Colleceted in Previous Year in MS11 Seamount

No.	Sampling No.	Depth (m)	Topographic Division	Cobalt Crust Type	Crust			Cobble Crust			Total		
					Amount (kg)	Max. (mm)	Min. (mm)	Amount (kg)	Max. (mm)	Min. (mm)	Amount (kg)	Max. (mm)	Min. (mm)
1	98SMS11LC01	4,353	W.lower slop										
2	98SMS11CB02	2,034	W.summit edge	cobble crust、nodule	0.80	25	15	16.94	110	60	17.74	110	49
3	98SMS11CB03	2,381	W.upper slop	crust fragment	0.26	20	5				0.26	20	5
4	98SMS11CB04	1,841	E.summit edge										
5	98SMS11CB05	1,818	W.summit edge	crustfragment									
6	98SMS11AD06	2,374	W.upper slop	crust	2.48	35	10				2.48	35	10
7	98SMS11AD07	2,077	W.summit edge	crust fragment	2.21	50	30				2.21	50	30
8	98SMS11AD08	1,952	E.summit edge	crust fargment、crust	2.64	90	20				2.64	90	20
9	98SMS11AD09	2,515	E.upper slop	crust、crust fragment	10.33	140	100				10.33	140	100
10	98SMS11AD10	2,667	N.middle slop	nodule、crust fragment	0.06	10	5				0.06	10	5
11	98SMS11LC11	1,670	E.summit edge										
12	98SMS11LC12	1,846	E.summit edge										
13	98SMS11AD13	1,921	S.summit edge	crust fragment	0.01	3	2				0.01	3	2
					Max.	140	100	Max.	110	60	Max.	140	100
					Ave.	60	30	Ave.	110	60	Ave.	74	36
											Ave.(summit)		33
											Ave. (slop)		38

・AD10 and AD13 were not included for average calculation, becaous only small amount of samples were collected at both sites.

Table 3-3-4-2 Sampling Results of Cobalt Crust in MS11 Seamount

No.	Drill Site	Drill Point	Depth (m)	Topographic Division	Sediments (m)	Cobalt Crust	Thickness (mm)	layers	Drill Core	Ave. Thickness (mm)	Bedrock	Seafloor
1	BMS01	02SMS11BMS01A	1,996	W. summit edge	1	crust、nodule	95	2		121	limestone	relatively flat、ER. 40%
2		02SMS11BMS01B	1,990	W. summit edge	0	crust	160	2			limestone	relatively flat、ER. 40%
3		02SMS11BMS01C	1,990	W. summit edge	0	crust	160	3			limestone	relatively flat、ER. 50-80%
4		02SMS11BMS01D	1,971	W. summit edge	130	crust	0,70	3			limestone	relatively flat、ER. 1-50%
5	BMS02	02SMS11BMS02A	1,983	SE. summit edge	1	crust	110	2		130	no sample	boulder like surface、ER. 60%
6		02SMS11BMS02B	1,980	SE. summit edge	0	crust、cobble crust	150	2			cal. congl.	boulder like surface、ER. 40%
7	BMS03	02SMS11BMS03A	2,750	NW. middle slop	0	crust	320		crushed	160	limestone	relatively flat、ER. 30-90%
8		02SMS11BMS03B	2,644	NW. middle slop	5	nodule、crust	160	3			limestone	boulder like surface、ER. 10%
9		02SMS11BMS03C	2,549	NW. middle slop	15	coating	0				limestone	relatively flat、ER. 10%
10	BMS04	02SMS11BMS04A	2,081	NE. summit edge	0	crust、nodule	130	2		145	no sample	boulder like surface、ER. 50%
11		02SMS11BMS04B	1,928	NE. summit edge	0	crust, nodul	160	2			cal. congl.、limestone	boulder like surface、ER. 90%
						Max.	320			160		
						Min.	0			121		
						Ave.	145			139		
						S.D.	95			17		
						Ave. (summit)				132		
						Ave. (slop)				160		

cal. congl: calcareous conglomerate, ER.: e

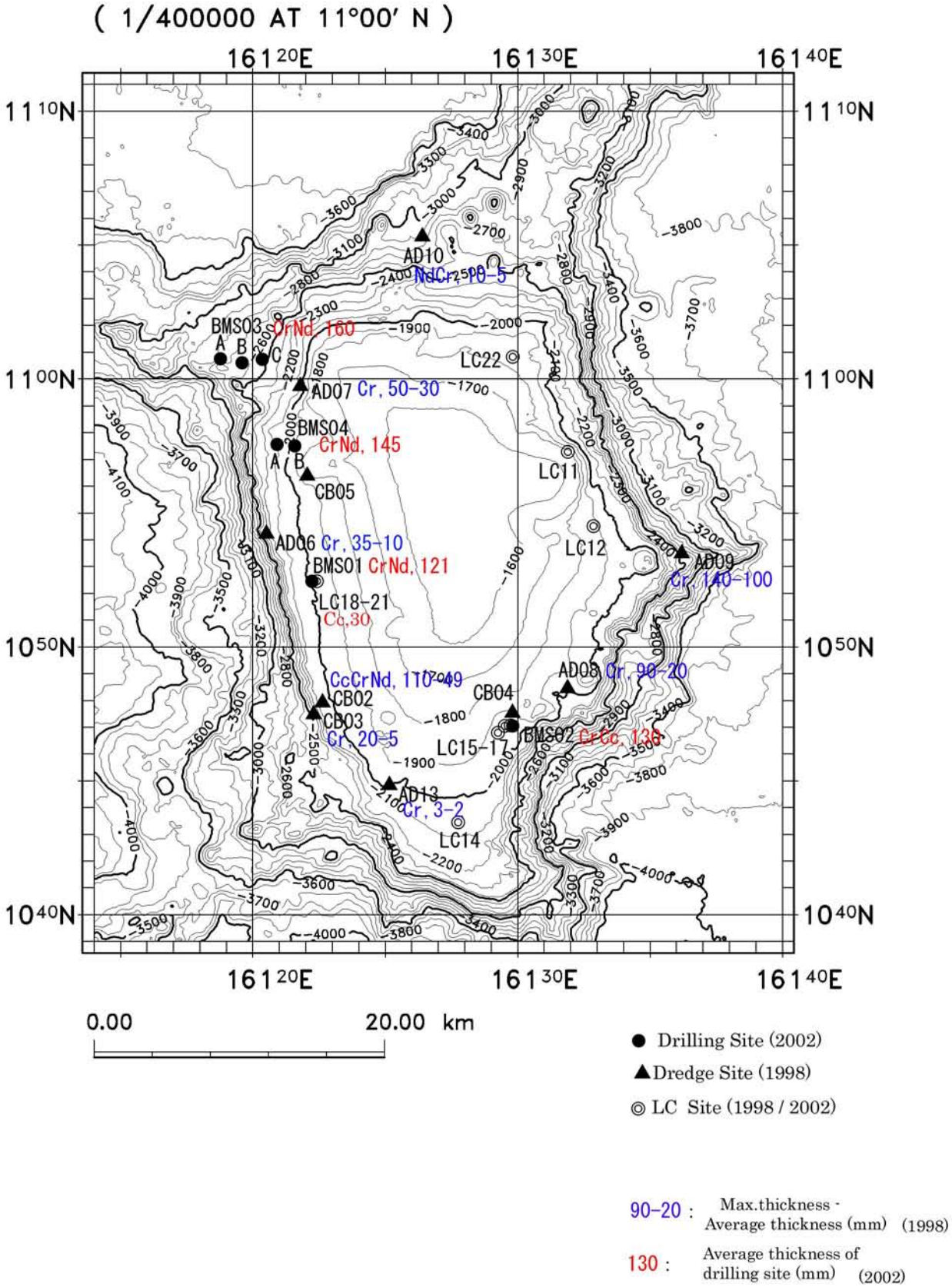


Figure 3-3-4-1 Thickness and Type of Cobalt Crust in MS11 Seamount

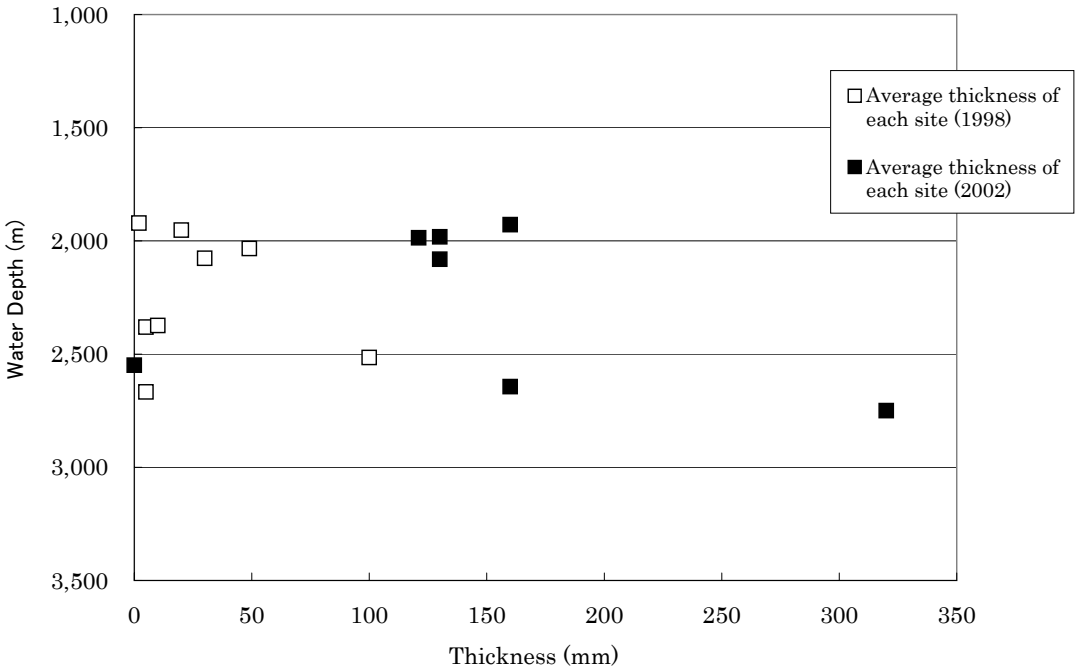


Figure 3-3-4-2 Thickness of Cobalt Crust and Water Depth of MS11 Seamount

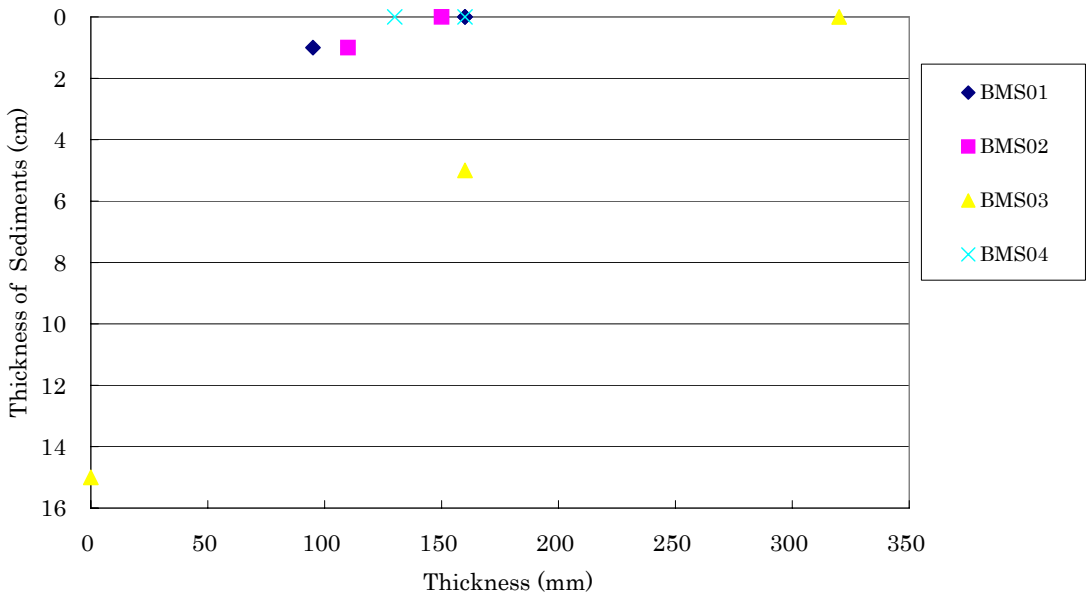


Figure 3-3-4-3 Thickness of Cobalt Crust and Sediments of MS11 Seamount

drilled. The thickness of cobalt crust obtained from the each drilling point shows wide range, from coated crust of less than 1mm to 320mm, and more than 100mm thick crust was obtained at 8 points. The average thickness of 11 points is 145mm.The variation of the thickness at each point is small at the BMS02 site and BMS04 site, but large at the BMS01 and BMS03 sites.

As is shown in Table 3-3-4-2 and Figure 3-3-4-3, the thickness of cobalt crust at the BMS03 site shows that at the point C where unconsolidated top sediments is 15cm thick, it is only coating thickness though other drilling point A and B is thick. At the BMS01D point, limestone is observed overlain by 130cm thick unconsolidated sediments but no crust is observed between the limestone and unconsolidated sediments. At all the points where unconsolidated sediments do not develop and the crust directly exposes on the surface, the thickness of the cobalt crust is 100mm or more. Average thickness of the cobalt crust at each site is calculated simply averaging 2 to 4 points of same site. The average thickness of the four sites, BMS01 to BMS04, is 121mm to 160mm, and the average thickness of all the sites is 139mm. The results of 1998 survey suggested an average thickness of 36mm for the MS11 seamount. Compared with results of 1998 and that of 2002, there is a big difference in thickness of cobalt crust.

In the survey of 1998, samples were obtained by dredging and the amount of sample was small, less than 3kg, except that obtained at the AD09, and almost all the sampling point contained fragments of crust (crust fragments without bedrock), that were inappropriate to use for the assumption of thickness. At the AD09 point, the amount of samples over 10kg was obtained and the average thickness of this site is 100mm.

The circumstances of exposure of cobalt crust at the MS11 seamount show two cases, comparatively flat seafloor and aggregates of boulder like rugged irregular surface, but clear relations between the circumstances of exposure and thickness of cobalt crust were found.

(2) Layer structure

In order to understand the historical sequence of cobalt crust growth, cobalt crust was described subdividing the layers of cobalt crust into seven types on the basis of visual appearance. The layer is named layer1, layer2, layer3, and so on from the outer side to inside. The subdivision of layer is shown in Figure 3-3-4-4.

The cobalt crust of the MS11 seamount shows comparatively similar, two to three layer structure. It shows similar, two layer, weakly mottled to columnar structure on the sample at the BMS01 and BMS02 site. The layer1 is Type 2, and the layer2 is black, compact Type 1. Other than that there is a case that layer1 shows a little oxidized,

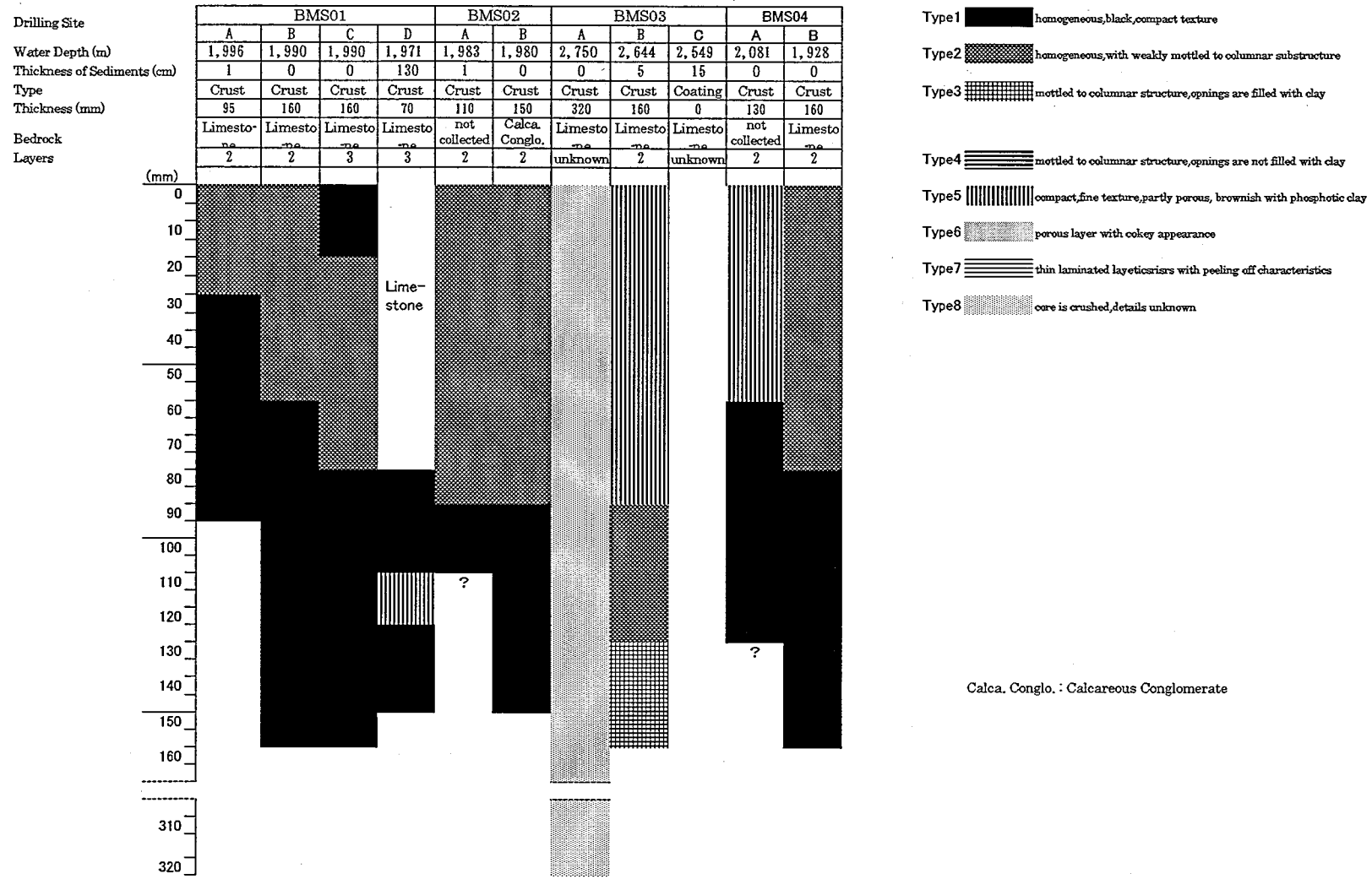


Figure 3-3-4-4 Layer Subdivision of Cobalt Crust of MS11 Seamount

brownish color classified into Type 5, but the inner layer shows black, compact Type1.

(3) Distribution of cobalt crust

At the summit of MS 11 seamount, there develop an area of exposed rocks between the water depth of 1,900m to 2,100m at the margin of the summit. In order to understand the distribution of cobalt crust in the summit area, drilling survey of eight holes at three drilling sites was conducted and average thickness of 121mm to 145mm was obtained In the survey of 1998, sampling by dredging at four sites in the summit area was done but the average thickness of each site was 2mm to 49mm, it is thin compared with the result of this year. The reason is that the amount of sample obtained by dredging was small, and could not obtain sufficient sample to represent the characteristics of the site. As samples of more than 100mm thick cobalt crust were obtained from six drilling points out of eight, a distribution of cobalt crust of thickness of more than 100mm in the exposed area of the summit is expected From the calculation of the drillings of three sites, the average thickness at the summit becomes 132mm.

In order to grasp the relation between the water depth and thickness, BMS03 site was selected at the middle slope and an average thickness of cobalt crust of 160mm was obtained. In the survey of 1998, the samplings at four sites were done from middle to upper slope. Of them collected samples at three points were small amount, and the thickness was 50mm to 100mm, and at the AD09 where sufficient amount of sample was collected, the thickness of 100mm was obtained as the average of the site. Judging from the result obtained at the BMS03 and AD09 sites, a distribution of cobalt crust with thickness more than 100mm is expected on the slope area as well as the summit area. To understand the relation of water depth and thickness of the cobalt crust, three drillings at the BMS03 site and two drillings at the BMS04 site with different water depth of about 100m were conducted. The thickness of three drilling points at the BMS03 varies greatly, from 0 to 320mm, and it seemed to be controlled by the factor other than depth of water. At the BMS04 site, the crust with similar thickness was obtained.

In order to confirm the horizontal succession of the cobalt crust at the exposed rock area, drilling at the southwestern part of the MS11 seamount with the water depth of 2,000m to 2,100m, where acoustic image showed dark tone, was planed, but it was canceled due to bad weather.

To confirm the occurrence of the cobalt crust beneath sediments coverage, detailed acoustic data was obtained and sampling was conducted at the west margin of the summit (Figure 3-3-2-4) and northeastern margin of the seamount (Figure 3-3-2-5). At

the west margin of the summit, the LC sampling of 4 sites was conducted from the summit area where shows low acoustic reflection intensity suggesting unconsolidated sediments to the slope area of higher acoustic reflection intensity, The four sites are LC18 (intermediate tone), LC19 (boundary of intermediate and dark tone), LC21 (dark tone), and LC21 (dark tone). At the point LC18, sample was not obtained but from seafloor photograph and no damage of the LC bit, unconsolidated sediments are expected at the site. Unconsolidated sediments of 90cm thick were collected at the LC19 site. At the LC20 and LC21 sites, the seafloor is covered with unconsolidated sediments but fragments of crust were collected, so that cobalt crust is expected overlain by thin sediments. At the BMS01D drilling conducted at the LC19 site, layered sample, consisting of limestone (8cm), crust (7cm) and limestone at the base, was collected covered by unconsolidated sediments of 130cm thick.

On the other hand, at the northeast of the summit, LC22 sampling was carried out at the area corresponds to the boundary of dark tone and light tone in the acoustic image, and unconsolidated sediments of 95cm was obtained. But at the area represented by intermediate tone, there develop unconsolidated sediments and its thickness is more than 1m. Near the boundary of intermediate and dark tone in the acoustic image, bedrock exists covered by unconsolidated sediments of 1.3m thick. Accordingly, in the area shown by dark tone in the acoustic image, the exposure of cobalt crust can be expected. But there are some cases such as BMS03C point, even it is located in the dark tone area, development of the cobalt crust is poor and covered by 15cm thick sediments.

3 – 3 - 4 - 2 Results of Chemical Analysis

For the samples obtained by the drilling survey at the MS11 seamount, chemical analyses for 20 samples (bulk sample: 10, layer-by-layer sample: 10) were conducted. Analyzed elements are 22 elements of Co, Ni, Cu, Mn, Fe, Pb, Zn, Ti, Mo, V, Si, Al, Ca, K, P, Ba, Sr, Pt, LOI, H_2O^+, $H_2O^-$and the following 14 rare earth elements of La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, a total of 36 elements. The analytical methods and the results are given in Appendix 8 and 11.

(1) Bulk sample

The statistical values of each element and major metal elements including Pt of the bulk samples were shown in Table 3-3-4-3 and Table 3-3-4-4. The histogram of the bulk sample and the dispersion diagram adding the results of the 1998 survey are given in Figure 3-3-4-5 and Figure 3-3-4-6.

Table 3-3-4-3 Chemical Characteristics of Cobalt Crust of MS11 Seamount

	Co %	Ni %	Cu %	Mn %	Fe %	Mn/Fe	Pb %	Zn %	Ti %	Mo %	V %	Si %	Al %	Ca %	Na %	K %	P %	Ba %	Sr %	Pt ppm
Max.	0.43	0.53	0.19	23.08	20.30	1.50	0.16	0.09	1.18	0.07	0.09	3.32	0.91	19.63	1.63	0.44	7.32	0.37	0.19	0.54
Min.	0.16	0.31	0.07	12.70	8.70	1.11	0.08	0.08	0.56	0.03	0.06	1.65	0.35	4.17	1.05	0.35	1.04	0.28	0.15	0.26
Ave.	0.33	0.38	0.11	19.06	14.70	1.31	0.13	0.08	0.86	0.05	0.08	2.35	0.64	11.11	1.38	0.40	3.76	0.31	0.17	0.39
S.D.	0.08	0.06	0.04	3.12	2.87	0.16	0.03	0.01	0.17	0.01	0.01	0.53	0.21	3.82	0.15	0.03	1.56	0.03	0.02	0.09
C.V.																				
C.V.	0.25	0.15	0.38	0.16	0.19	0.12	0.20	0.06	0.20	0.24	0.15	0.23	0.33	0.34	0.11	0.07	0.42	0.10	0.09	0.25

	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	ΣREE ppm
Max.	492	1660	77.5	336.0	60.3	15.8	75.8	10.9	63.3	13.0	38.2	5.1	33.2	5.3	2846.2
Min.	295	771	32.4	144.5	22.9	6.7	37.0	5.0	33.9	8.3	26.3	3.6	23.5	3.8	1469.8
Ave.	372	1374	51.1	222.2	39.3	10.8	53.1	7.5	44.8	9.8	30.0	4.1	27.2	4.4	2250.1
S.D.	54	319	11.6	49.1	9.2	2.3	10.0	1.5	7.8	1.4	4.0	0.5	3.2	0.5	422.3
C.V.	0.14	0.23	0.23	0.22	0.23	0.21	0.19	0.20	0.17	0.15	0.13	0.12	0.12	0.11	0.19

N=10
(bulk samples)

Table 3-3-4-4 Grade of Cobalt Crust of MS11 Seamount

	Drill Site	Drill Point	Depth	Thickness (mm)	Co %	Ni %	Cu %	Mn%	Fe %	Mn/Fe	Pt ppm	Ave. Depth (m)	Max. Thickness (mm)	Ave. Thickness (mm)	Ave. Co %	Ave. Ni%	Ave. Cu%	Ave. Mn %	Ave. Fe%	Ave. Fe/Mn	Ave. Pt ppm
1	BMS01	A	1, 996	95	0. 30	0. 39	0. 12	17. 73	13. 90	1. 28	0. 51	1, 987	160	121	0. 29	0. 35	0. 09	17. 31	13. 48	1. 30	0. 41
2		B	1, 990	160	0. 34	0. 33	0. 11	19. 44	16. 30	1. 19	0. 43										
3		C	1, 990	160	0. 34	0. 31	0. 07	19. 36	15. 00	1. 29	0. 33										
4		D	1, 971	70	0. 16	0. 40	0. 07	12. 70	8. 70	1. 46	0. 39										
5	BMS02	A	1, 983	110	0. 25	0. 53	0. 19	16. 11	13. 60	1. 18	0. 54	1, 982	150	130	0. 34	0. 46	0. 14	18. 85	14. 00	1. 34	0. 40
6		B	1, 980	150	0. 43	0. 40	0. 09	21. 60	14. 40	1. 50	0. 26										
7	BMS03	A	2, 750	320	0. 43	0. 38	0. 12	23. 08	20. 30	1. 14	0. 31	2, 697	320	160	0. 37	0. 36	0. 15	20. 40	18. 15	1. 12	0. 38
8		B	2, 644	160	0. 31	0. 34	0. 18	17. 73	16. 00	1. 11	0. 45										
9	BMS04	A	2, 081	130	0. 39	0. 40	0. 09	21. 91	14. 60	1. 50	0. 29	2, 005	160	145	0. 38	0. 40	0. 09	21. 45	14. 40	1. 49	0. 33
10		B	1, 928	160	0. 37	0. 40	0. 09	20. 98	14. 20	1. 48	0. 37										
			Samples	10	10	10	10	10	10	10	10		4	4	4	4	4	4	4	4	4
			Max.	320	0. 43	0. 53	0. 19	23. 08	20. 30	1. 50	0. 54		320	160	0. 38	0. 46	0. 15	21. 45	18. 15	1. 49	0. 41
			Mini.	70	0. 16	0. 31	0. 07	12. 70	8. 70	1. 11	0. 26		150	121	0. 29	0. 35	0. 09	17. 31	13. 48	1. 12	0. 33
			Ave.	152	0. 33	0. 38	0. 11	19. 06	14. 70	1. 31	0. 39		198	139	0. 34	0. 39	0. 12	19. 50	15. 01	1. 31	0. 38
			S.D.	67	0. 08	0. 06	0. 04	3. 12	2. 87	0. 16	0. 09		82	17	0. 04	0. 05	0. 03	1. 81	2. 13	0. 15	0. 04
			C.V.	0. 44	0. 25	0. 15	0. 38	0. 16	0. 19	0. 12	0. 25		0. 41	0. 12	0. 13	0. 13	0. 27	0. 09	0. 14	0. 11	0. 09
									Results of 1998			Samples	7	7	7	7	7	7	7	7	7
												Ave.	65	31	0. 69	0. 47	0. 05	21. 49	14. 95	1. 45	0. 65
									Ave. Central Pacific *			Samples			308	311	265	311	311	311	29
												Ave.			0. 79	0. 47	0. 12	23. 00	15. 70	1. 39	0. 24

*Average value of the Central Pacific Crust (Hein et al. 1992)

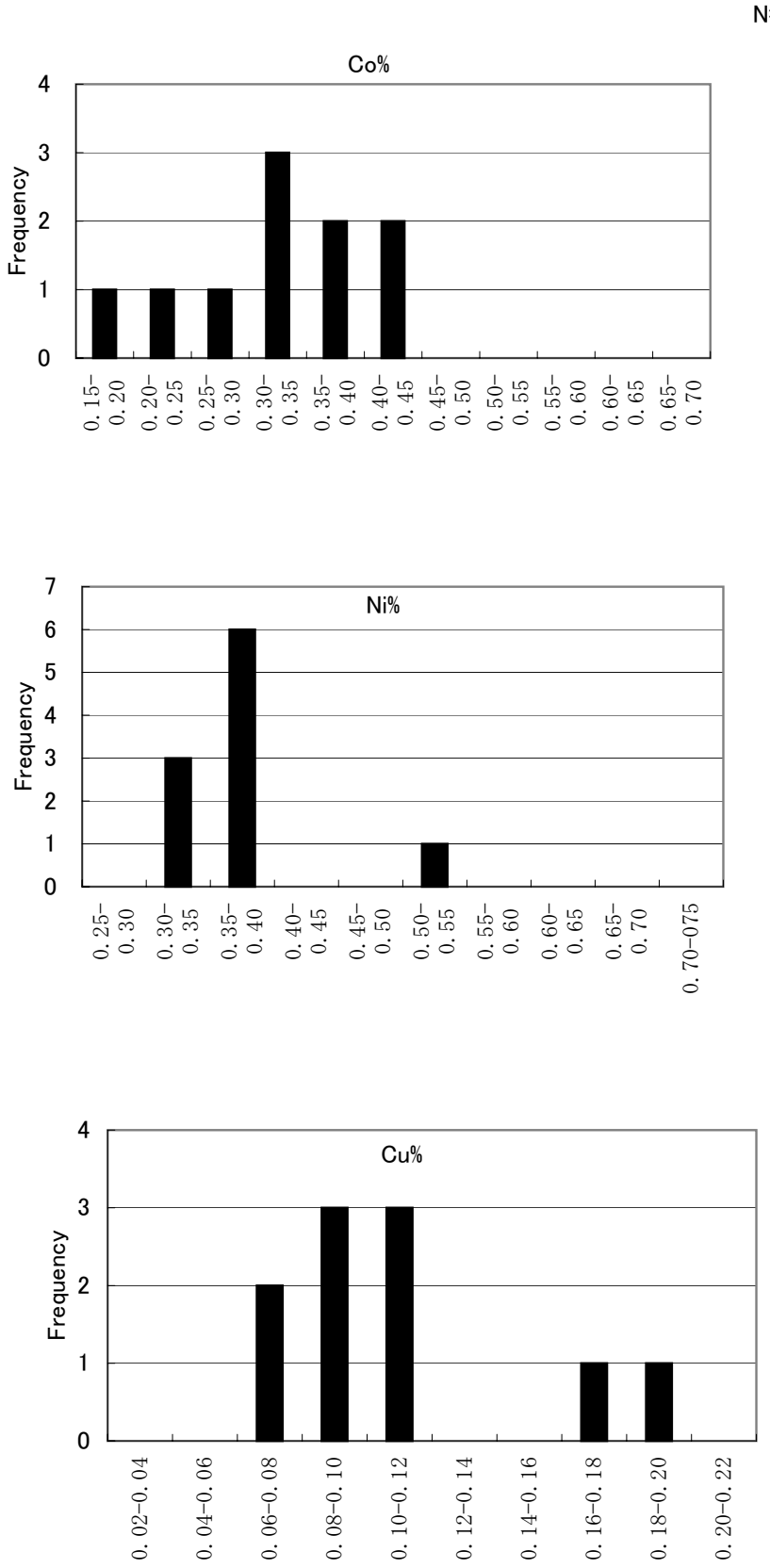


Figure 3-3-4-5 Assay Results Histgram of MS11 Seamount
(1/2)

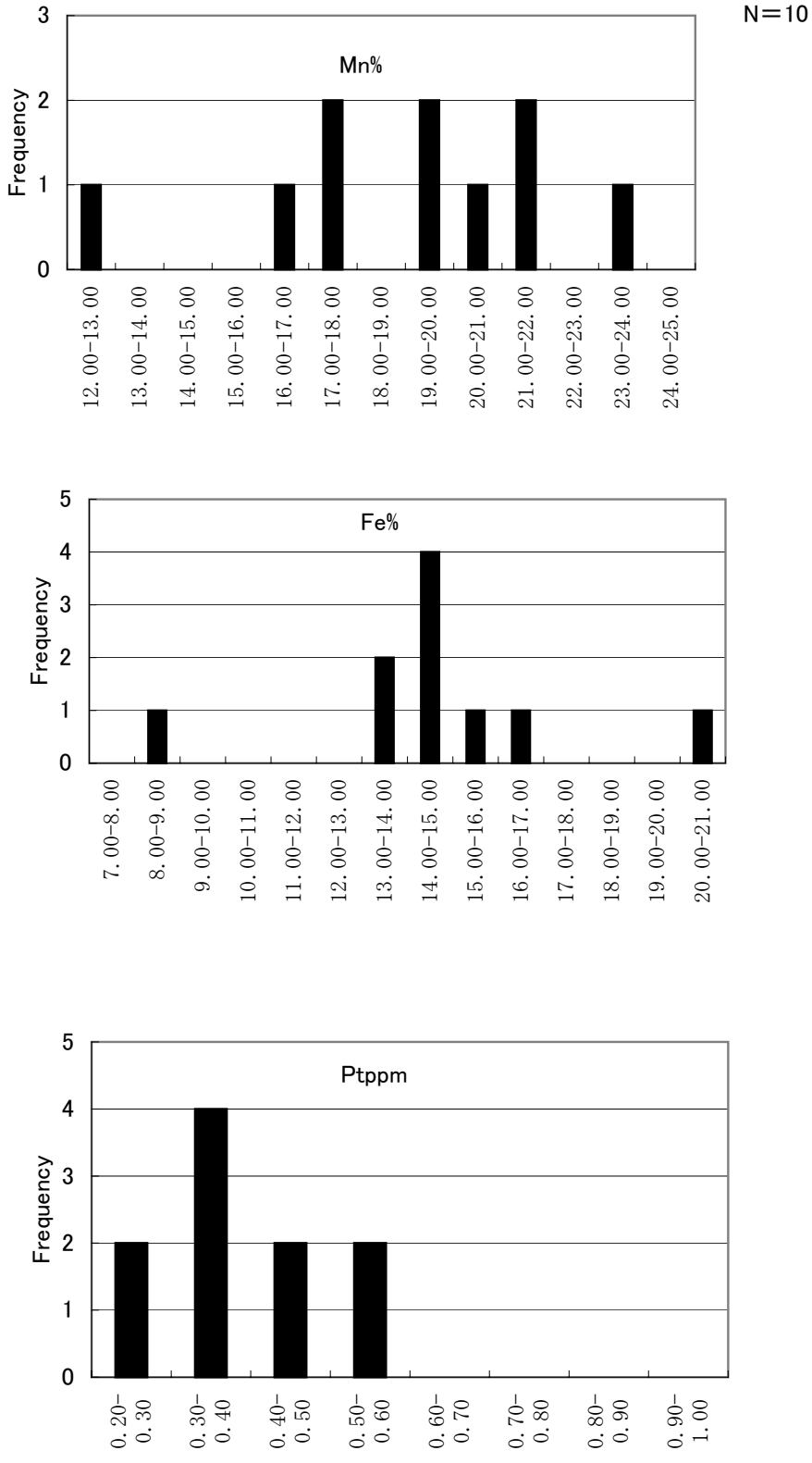


Figure 3-3-4-5 Assay Results Histgram of MS11 Seamount
(2/2)

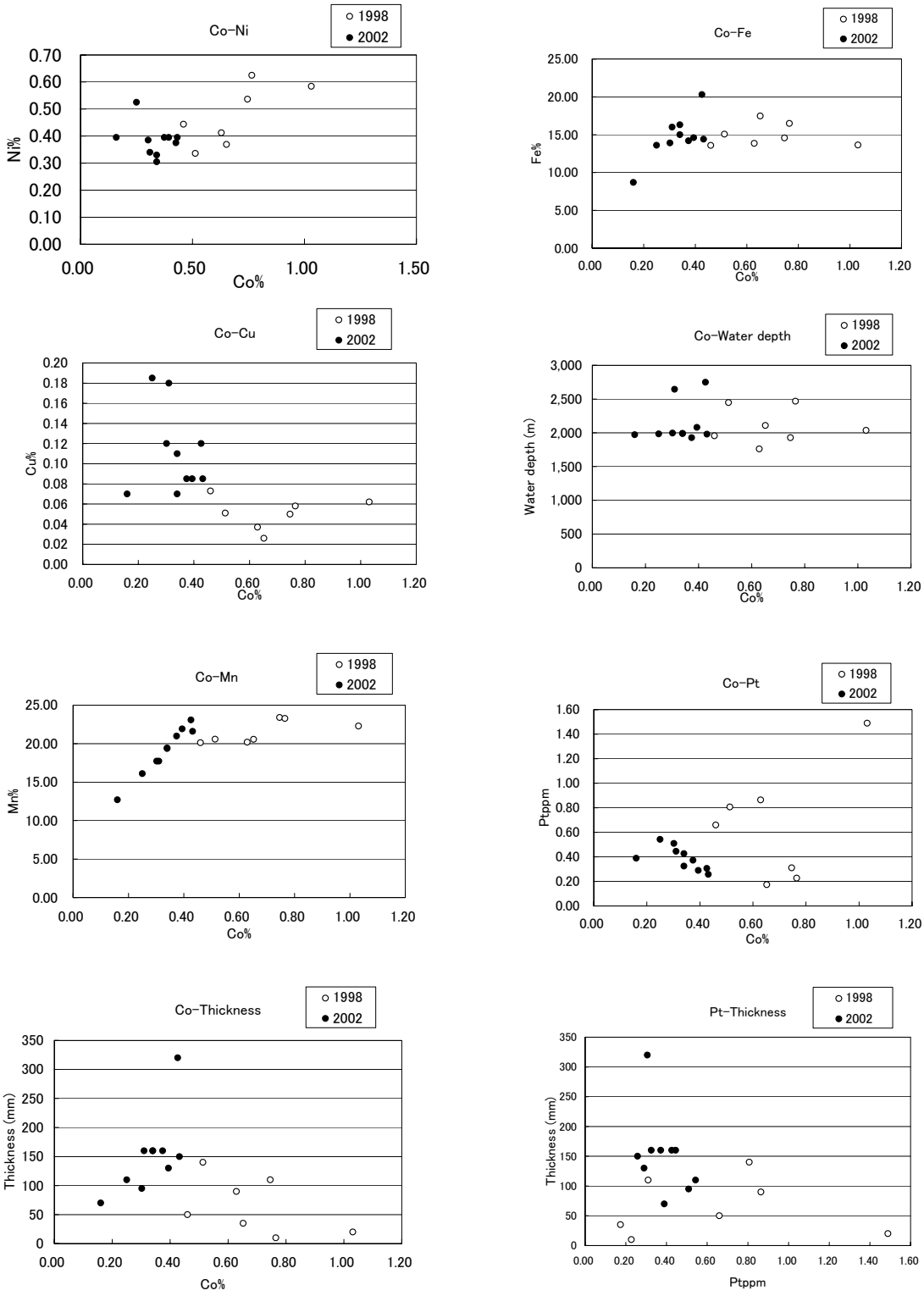


Figure 3-3-4-6 Dispersion Diagram of Assay Results of MS11 Seamount

The content of Co in the 10 bulk samples shows 0.16% to 0.43%, mainly 0.30% to 0.40%. On Ni, almost all samples show the value near the average, 0.38%, but Cu and Mn have wide range, 0.07% to 0.19% and 12.70% to 23.08%, respectively. Fe has wide value range, 8.70% to 20.30% but mostly shows about 14.00%. The content of Pt is 0.26ppm to 0.54ppm. The differences of grade among points (e.g. drill holes A. B, C) are comparatively small, so that average grade of each site (e.g. BMS01) was obtained by averaging the grade of each point.

The average chemical content of the cobalt crust at the MS11 seamount obtained by the survey of this year, is Co 0.34%, Ni 0.39%, Cu 0.12%, Mn 19.50%, Fe 15.01%, and Pt 0.38ppm. Compared with the results of 1998, the content of Co and Pt are low, and Cu is high. There is no marked difference in Ni, Mn, and Fe. Compared with the average of Central Pacific crust (Hein et al., 1992), Co is low and Pt is a little high.

In the dispersion diagram, only the results of this year shows positive correlation for Co-Mn, and Co-Fe, but it is not observed in the survey result of 1998. There exists negative correlation for Co-Cu. There is no marked relation between water depth and Co, but there is negative correlation between the layer thickness and Co in the survey result of 1998, showing thicker the layer, poorer the grade of Co.

Other than above elements, the average content of metal elements, Pb, Zn, and Mo are 0.13%, 0.08%, and 0.05%, respectively. The content of Ca and P shows wide range, 4.17% to 19.63% and 1.04% to 7.32%, and average is high, 11.11% and 3.76%. Both elements show very good correlation.

On the rare earth elements of the bulk sample, the average ΣREE is 2,250ppm, and it has broad range, 1,469 ppm to 2,846ppm. This is due to the variation of Ce, from 771ppm to 1,660ppm. In the North American standard shale normalized diagram, it shows flat pattern, and concentration of 4 to 10 times of shale with positive anomaly of Ce. This pattern is similar to that of hydrogenetic crust of the seamounts in the Pacific region (Usui and Someya, 1997).

(2) Layer-by-layer sample

Layer-by-layer analysis on the sample of the MS11 seamount was conducted, but the number of sample is small and no systematic relation between the layer and the chemical composition was found.

(3) Grade and thickness

The distribution of grade of the cobalt crust at the sampling sites is shown in Figure 3-3-4-7 together with the thickness of the crust. The thickness of the cobalt crust of 1998 survey, obtained by dredging and the LC sampling, is shown by the maximum thickness of each site.

As the result of the survey of this year, the average grade of the cobalt crust obtained from the three sites at the summit area by the drilling survey shows, low grade, Co content of 0.29% to 0.38 % and average grade is 0.34%. There is no specific relation on the distribution of the Co grade, and cobalt crust with Co grade of 0.34% is considered to be widely distributed over the summit area. The grade of Co of one drill site at the slope is 0.37%, and there is no marked difference with other data of the summit area. The thickness of the cobalt crust at the three sites at the summit shows similar value from 121mm to 145mm, and the average thickness is 132mm. The thickness of the one drilling site at the slope is 160mm, and slightly thicker than those at the summit.

As the result of the survey of 1998, the average Co grade of 0.66% was obtained and this is higher than the result of this year. One of the reasons for this is assumed to be that dredging and the LC samplings conducted in 1998 collected incomplete crust samples without whole layers from surface to bedrock This is evident from the view point of the thickness of the crust, that is, in the survey of 1998, the average of even the maximum thickness was 74mm and this is about the half of the thickness obtained this year, 139mm. As shown by the layer-by-layer analysis results of the MS01 seamount, the grade of Co of the outer layer is high, and decreases toward inner layer.

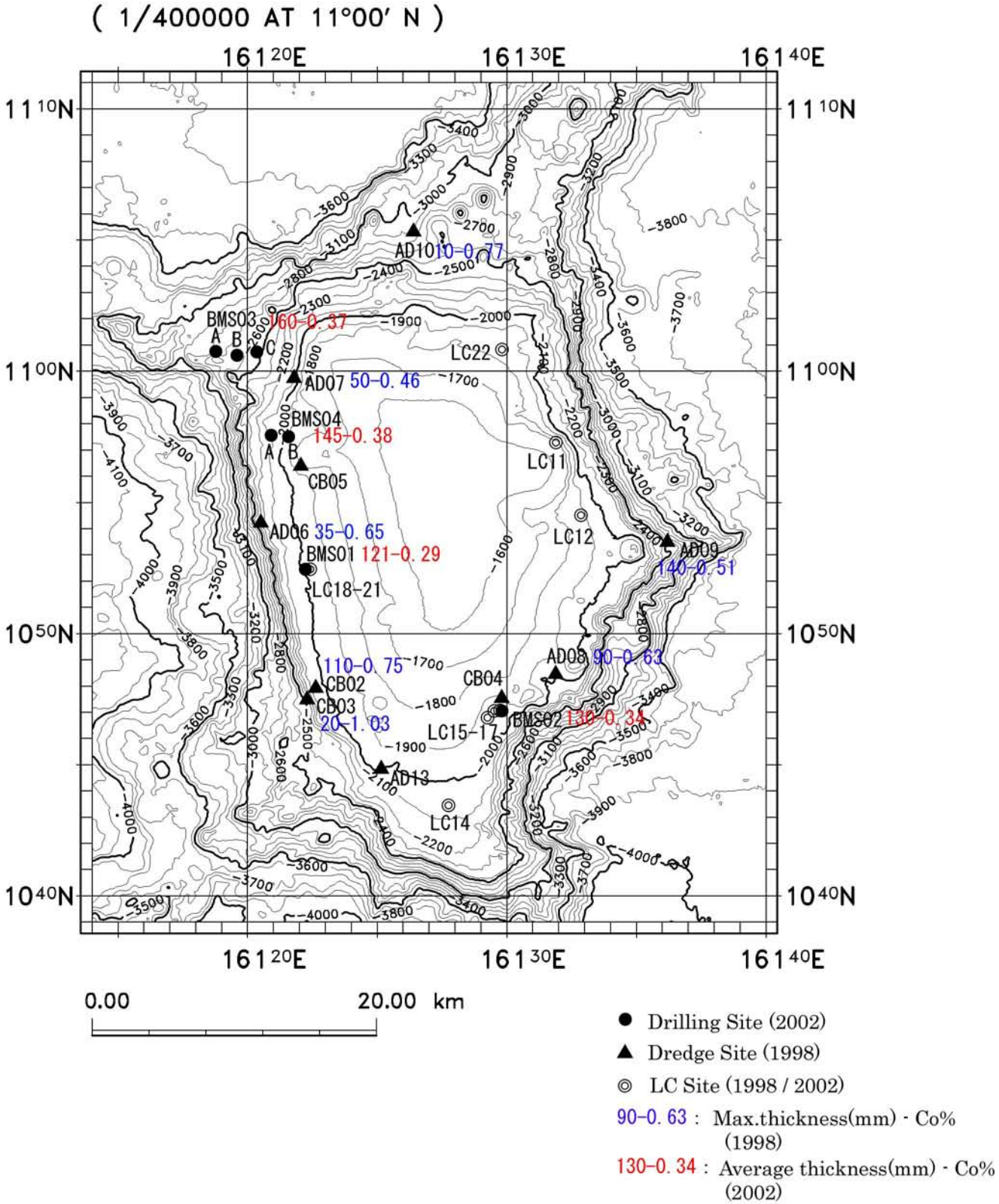


Figure 3-3-4-7 Co Grade and Thickness of Cobalt Crust in MS11 Seamount

3 - 4　MS12 Seamount

In the survey of 1998, acoustic survey including MBES, dredging, and sampling by LC were conducted at the MS12 seamount. In this year, supplementary acoustic survey taking the subordinate track lines for the purpose of the improvement of the accuracy of topographic map and drilling by BMS and LC sampling were conducted.

3 - 4 - 1　Topography and Circumstances of Seafloor

Acoustic survey was completed in 1998, and there is not much amount of newly obtained information. The bathymetric map adding the data of this year and the MBES acoustic image are shown in Figure 3-4-1-1 and Figure 3-4-1-2.

3 - 4 - 1 - 1　Topography

The MS12 seamount is an isolated flat seamount having its center at 8° 50'N, 163° 12'E and situated southeast of Anewetak Atolls.

The shallowest water depth at the summit is 1,037m and the relative height from the base to the summit is about 3,900m. The summit area has elliptical shape with long axis of 25km to WNW-ESE direction and short axis of 15km, but the basal part shows circular shape. The area of the summit, shallower than water depth of 1,400m, is 295km^2. The summit area is, excluding pinnacles at the south, covered widely with unconsolidated sediments, and the thickness reaches more than 100m at the central part. For this, seafloor topography of the summit area is quite smooth and the relative height from the margin of the summit to the top of the summit is 300m, showing gentle dome like topography with the slope angle at the summit area of less than 4 degrees.

At the slope of the seamount, ridges extend to the long axis direction and the crossing southwestern direction, and the area between slops shows a horse-shoe shape valley. The area deeper than water depth of 3,000m becomes gentle slope and forms terrace. The average inclination of the slope area is, 21.0 degrees at the upper slope, 17.9 degrees at the middle part, and 10.5 degrees at the lower part. The slope becomes gradually gentle from the upper part to the lower part. At the north and east of the seamount, intricate valley and ridge features develop from the middle part of the slope to the deeper part, and many small-scale pinnacles are seen.

3 - 4 - 1 - 2　Circumstances of Seafloor

There develop wide extension of unconsolidated sediments at the summit area, and forms quite smooth gentle dome-like topography. But the acoustic reflection intensity distribution of the central part of the summit is not uniform, and the intensity level

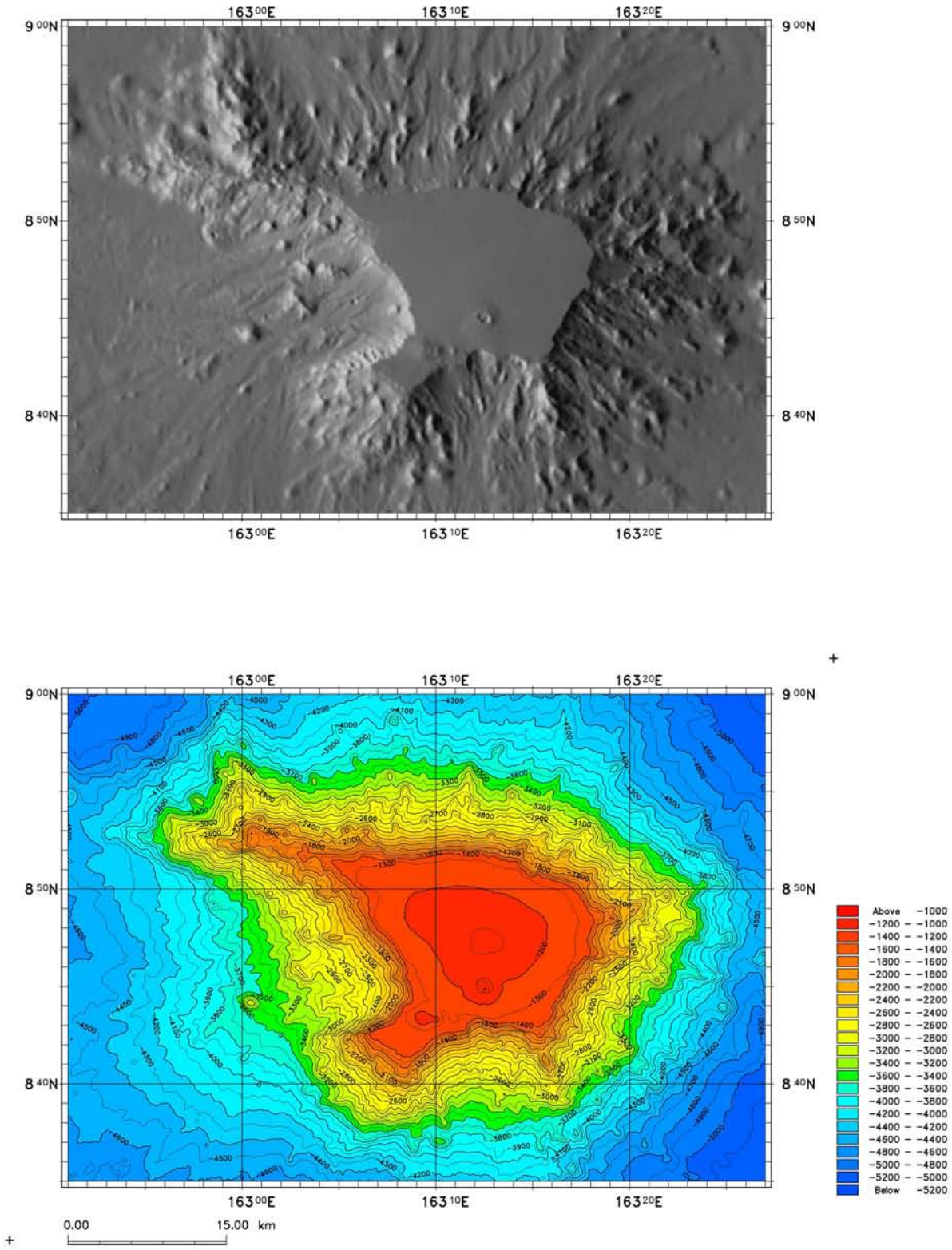


Figure 3-4-1-1 Bathymetric Map and Shaded Map of MS12 Seamount

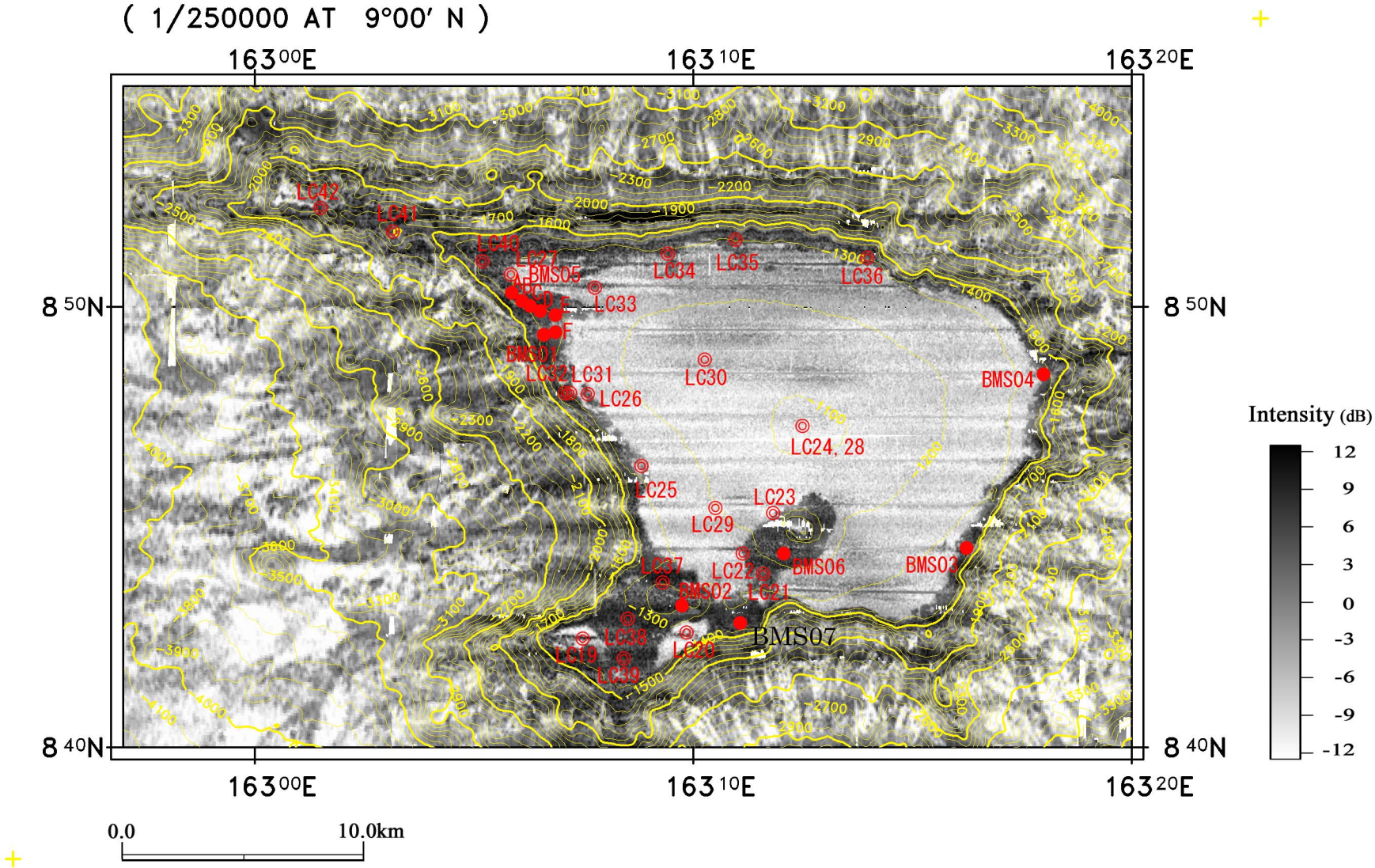


Figure 3-4-1-2 Acoustic Reflection Intensity Distribution of MS12 Seamount

changes correspond to the thickness of the sediments. That is, at the shallowest part where the thickness of sediments is greater than 100m, the acoustic image shows light tone, but at the north of the summit area and the area adjacent to pinnacles, where is assumed to have thin sediments, the image shows darker tone.

On the slope, the dark and light tone appears repeatedly corresponding to ridge and valley, and generally the acoustic reflection intensity becomes weaker from the upper to the lower. But, at the slope of the east and southeast of the summit, the upper part of the slope shows light tone suggesting deposition of unconsolidated sediments. In the west, a terrace topography extending in the area water depth 3,000m to 4,000m, there develop light tone area suggesting sediments.

According to the SBP survey conducted in1998, the summit area is generally covered with unconsolidated sediments except the pinnacle near 8° 50'N and a stage like portion extending toward north and south at the western side of the seamount, and the sediments increase the thickness from the shoulder part to the central part, and the maximum thickness reaches more than 120m. At the margin of the summit, the east and south side is covered with sediments up to the shoulder part, but the west and north side consist of exposed rocks. The sediments at the slope are generally thin, and particularly north and west slope seem to be exposed area up to the middle part of slope.

3 - 4 – 2 Results of Sampling

At the MS12 seamount, dredging of 15 points by the AD (arm dredge) and LC sampling at 3 points, and two FDC observations along two track lines were done (Table 3-4-2-1). As the result, average thickness of the cobalt crust of 39mm,with average Co grade of 0.69%, were obtained. In the survey of this year, drilling of 25 holes at seven sites from MS11BMS01 to MS11BMS07, and LC sampling of 24 sites were carried out.

The sampling location map, location of drilling point, core correlation photographs and the results of sampling are shown in Figure 3-4-2-1, Figure 3-4-2-2, Figure 3-4-2-3 and Table 3-4-2-2, respectively. Additional data, such as photographs of seafloor of the drilling points, photographs of drill cores, columnar profile of drilling cores, photographs of seafloor of LC and MC sites and columnar profile of LC and MC are given in Appendix 1 to 5.

In order to understand horizontal continuity of cobalt crust distribution, drilling of 6 holes and seafloor observation by TV camera installed in the BMS were conducted at BMS05 site. The results of seafloor observation at BMS05 site are given in Figure 3-4-2-4.

Table 3-4-2-1 Sampling Results of Previous Year in MS12 Seamount

No.	Sampling No.	Bottom Touch			Bottom Release			Topographic Division	Length /Amount (cm)/(kg)	Rock	Mn Crust
		Latitude	Longitude	Depth (m)	Latitude	Longitude	Depth (m)				
1	98SMS12LC01	8°48.006′ N	163°30.030′ E	4,528				E.foot	335cm	Clay, basalt	nodule
2	98SMS12AD02	8°44.310′ N	163°08.542′ E	1,554	8°44.209′ N	163°08.691′ E	1,386	W.upper slop	120.65kg	conglomerate	crust, crust frog.
3	98SMS12AD03	8°42.977′ N	163°12.584′ E	1,555	8°44.209′ N	163°08.691′ E	1,446	S.upper slop	4.95kg	conglomerate, basalt	crust
4	98SMS12AD04	8°42.210′ N	163°14.860′ E	1,974	8°42.038′ N	163°14.860′ E	1,857	S.upper slop	65.14kg	basalt, tuff breccia	crust
5	98SMS12AD05	8°42.310′ N	163°14.844′ E	1,719	8°42.227′ N	163°15.157′ E	1,639	S.upper slop	6.16kg	limestone, pumice, basalt	crust
6	98SMS12AD06	8°47.695′ N	163°06.547′ E	1,689	8°47.494′ N	163°07.183′ E	1,487	W.uuper slop	0.29kg	limestone, basalt, pumice	crust fragment
7	98SMS12AD07	8°47.495′ N	163°07.244′ E	1,448	8°47.470′ N	163°07.852′ E	1,250	W.uuper slop	194.80kg	basalt	cobbly crust
8	98SMS12AD08	8°49.465′ N	163°04.980′ E	2,060	8°49.553′ N	163°05.210′ E	1,892	W.uuper slop	17.90kg	limestone, pumice, basalt	crust, crust fragment
9	98SMS12AD09	8°48.761′ N	163°05.804′ E	1,796	8°48.852′ N	163°06.519′ E	1,399	W.uuper slop	2.02kg	basalt, tuff, limestone	crust fragment, nodule
10	98SMS12AD10	8°49.602′ N	163°05.828′ E	1,499	8°49.575′ N	163°06.193′ E	1,438	W.uuper slop	1.04kg	basalt, pumice	crust
11	98SMS12AD11	8°51.453′ N	163°08.759′ E	1,342	8°51.391′ N	163°09.246′ E	1,260	N.summit edge	6.64kg	hyaloclastite	crust,cobbly crust
12	98SMS12AD12	8°52.636′ N	163°11.679′ E	1,983	8°52.453′ N	163°12.351′ E	2,039	N.upper slop	1.67kg	basalt, pumice	crust,crust fragment
13	98SMS12AD13	8°52.049′ N	163°11.715′ E	1,716	8°51.953′ N	163°12.194′ E	1,497	N.upper slop	27.20kg	conglomerate, basalt	crust
14	98SMS12LC14	8°45.035′ N	163°12.464′ E	1,130				N.summit	unknown	foraminifera clay	
15	98SMS12LC15	8°43.616′ N	163°16.045′ E	1,372				E.summit edge	-		
16	98SMS12AD16	8°39.587′ N	163°07.930′ E	2,268	8°39.833′ N	163°08.414′ E	2,054	S.middle slop	97.70kg	basalt, conglomerate	crust, cobbly crust
17	98SMS12AD17	8°42.911′ N	163°10.270′ E	1,273	8°43.275′ N	163°10.655′ E	1,279	S.middle slop	118.18kg	basalt, conglomerate	cobbly crust, nodule
18	98SMS12AD18	8°44.322′ N	163°11.676′ E	1,157	8°44.498′ N	163°12.132′ E	1,097	summit center	1.84kg	tuff, limestone	crust, nodule

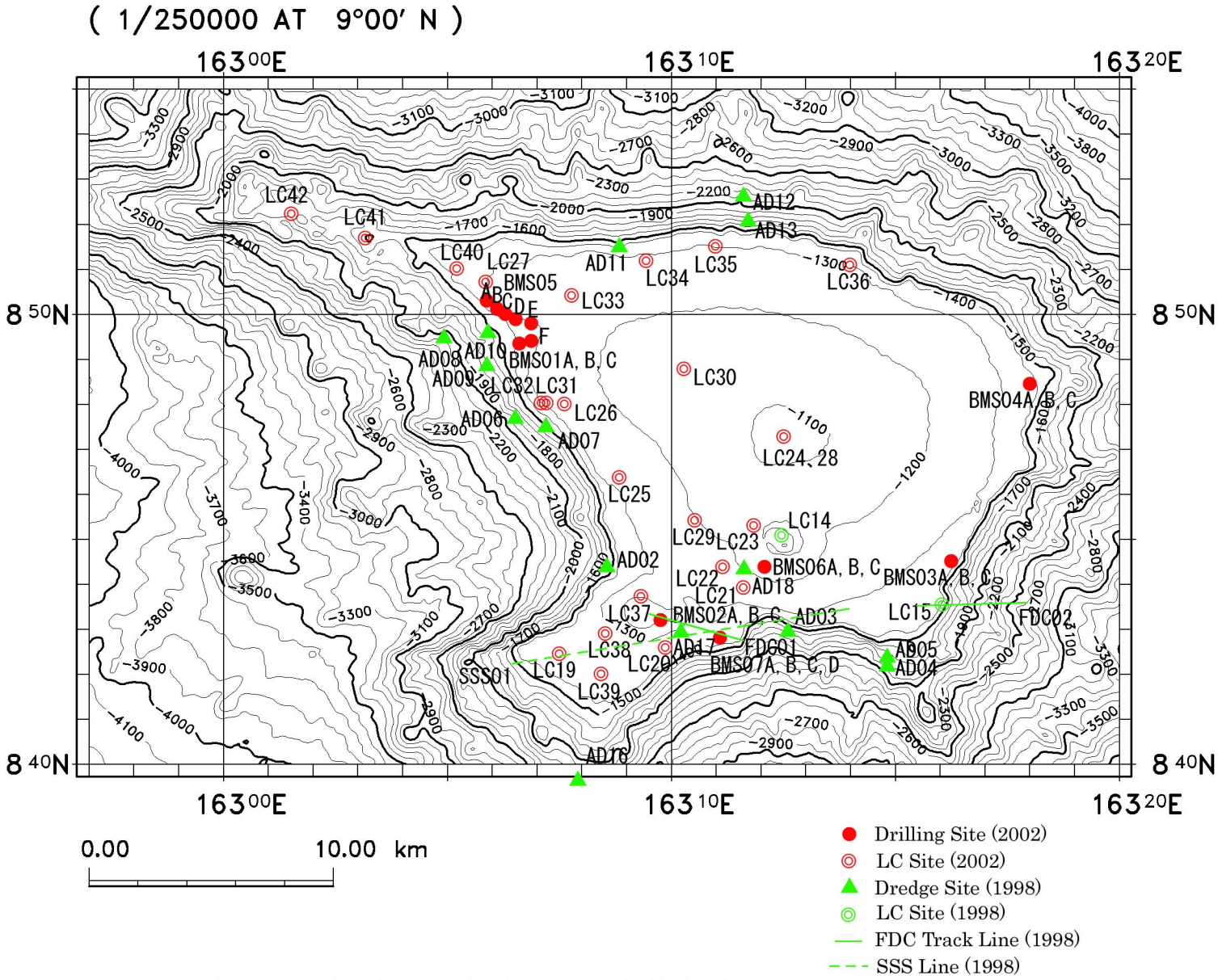


Figure 3-4-2-1 Sample Location of MS12 Seamount

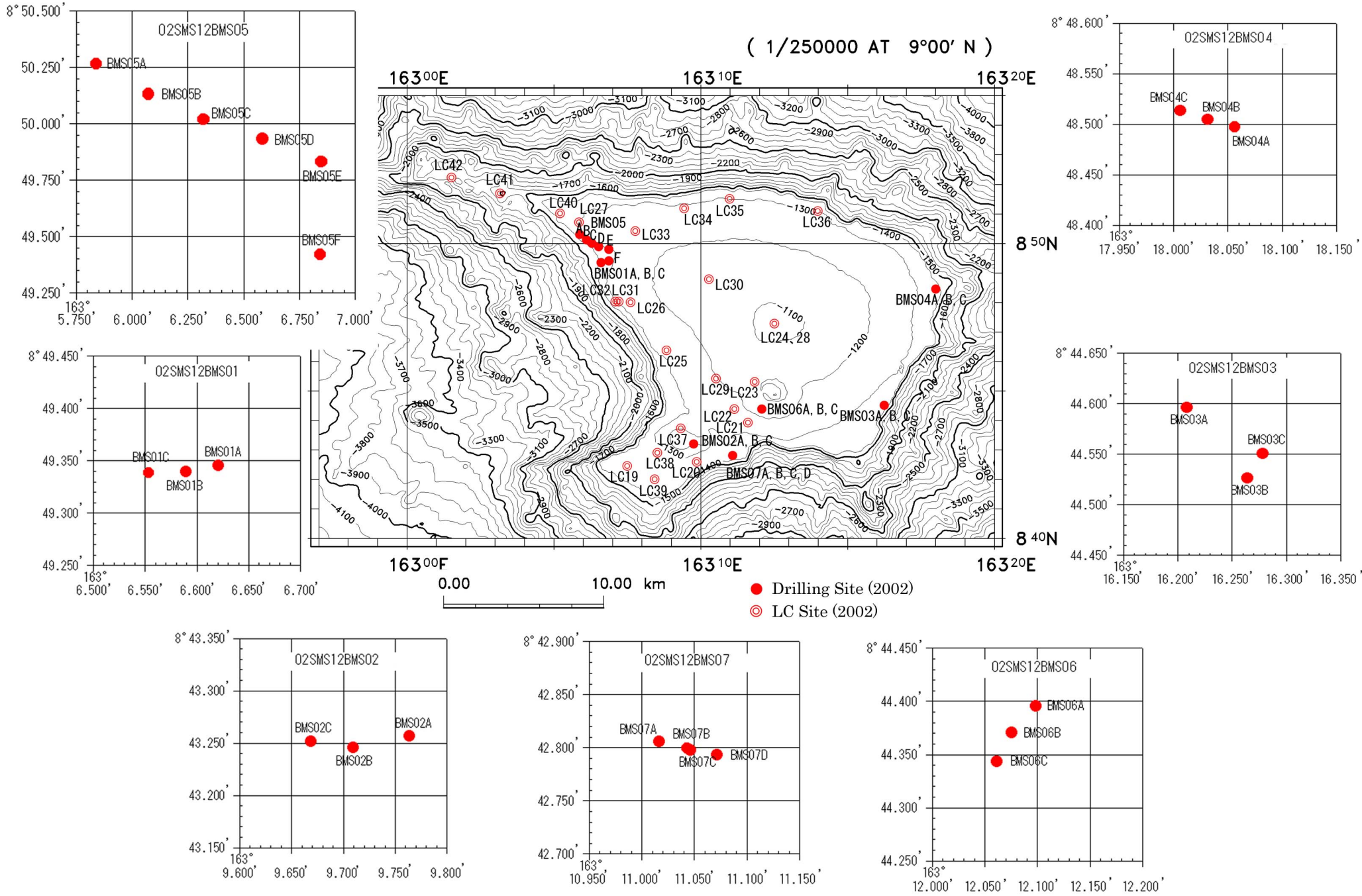


Figure 3-4-2-2 Location of Drilling Point in MS12 Seamount

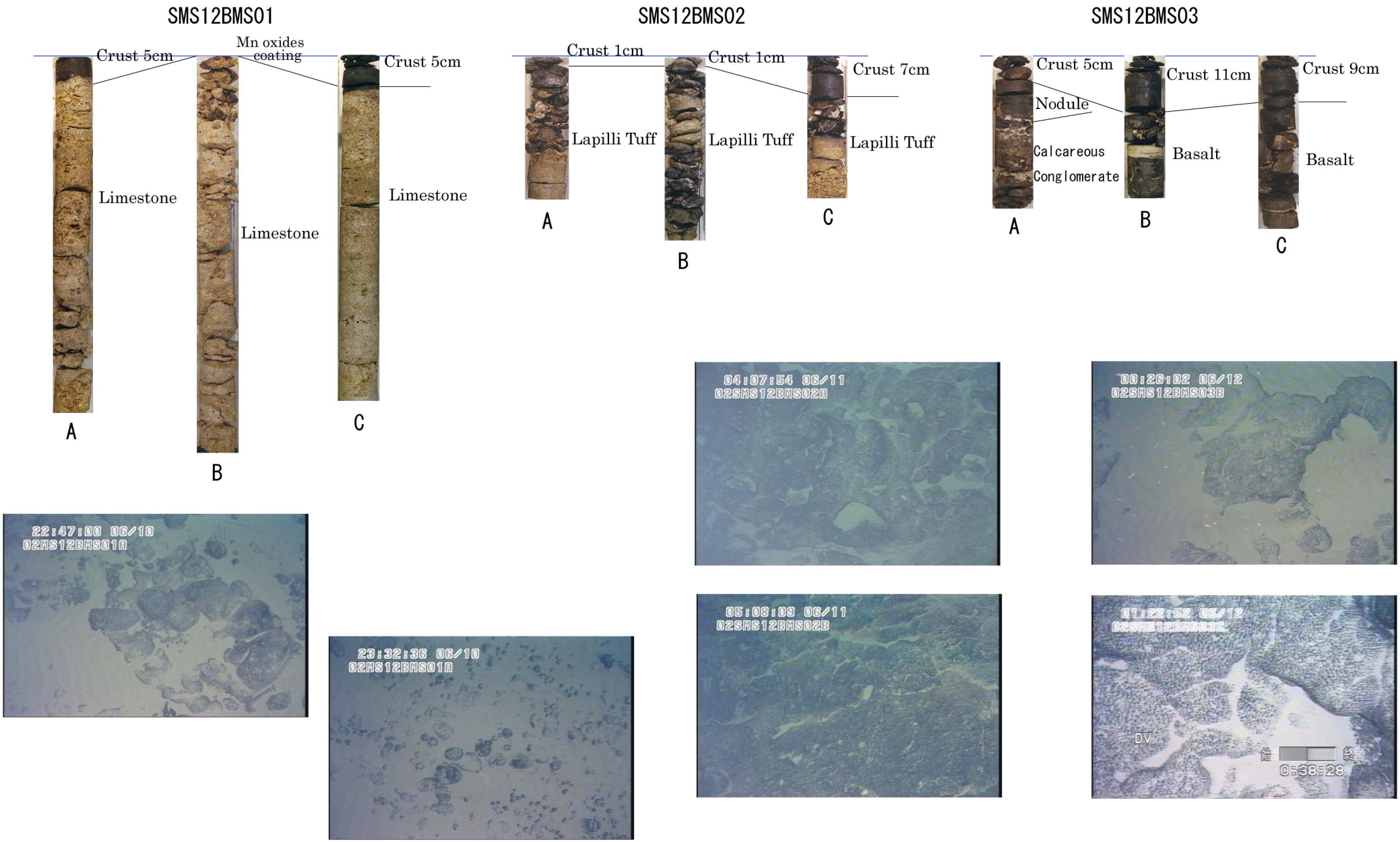


Figure 3-4-2-3 Correlation Core Photographs of MS12 Seamount (1)

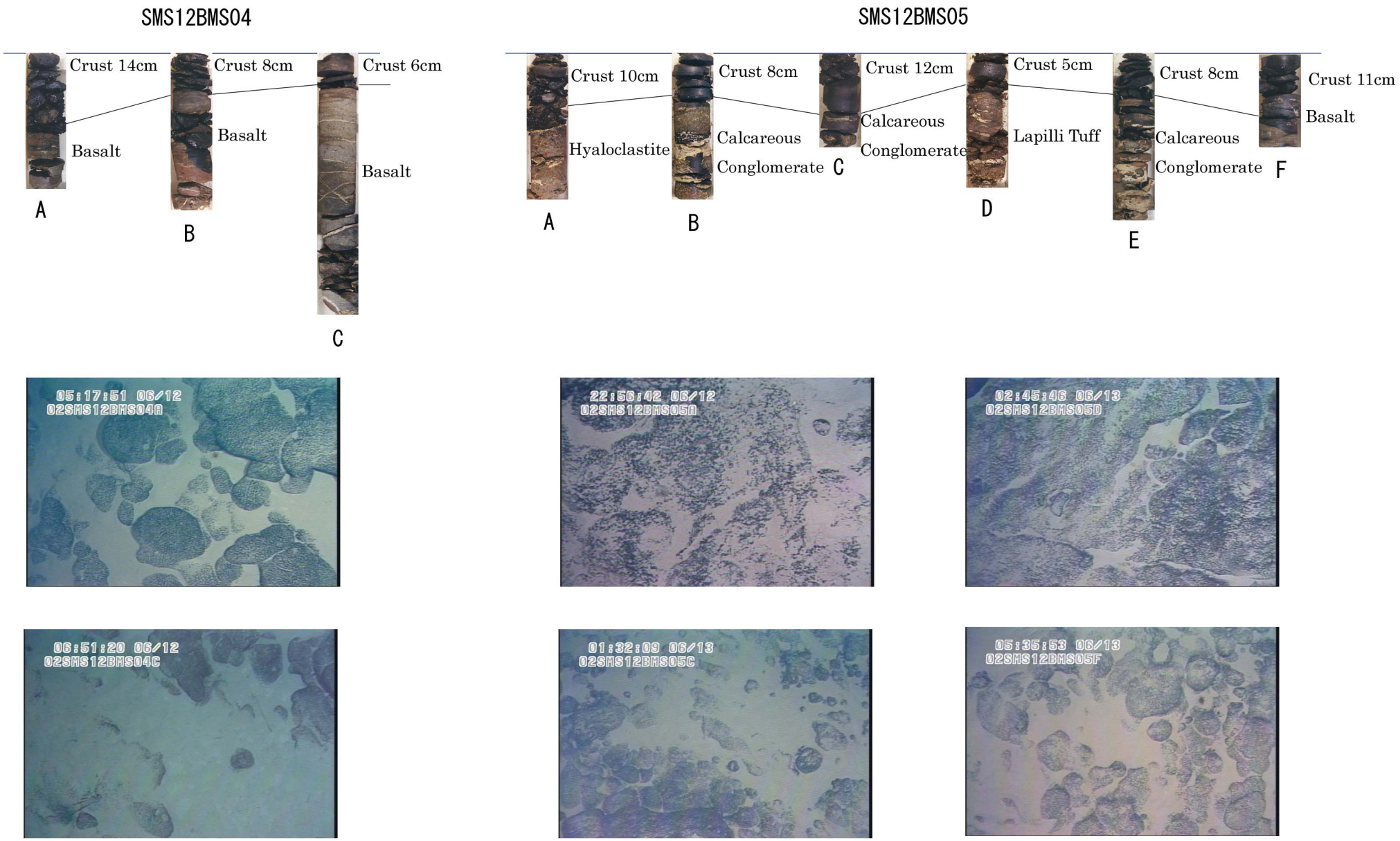


Figure 3-4-2-3 Correlation Core Photographs of MS12 Seamount (2)

Table 3-4-2-2 Sampling Results of MS12 Seamount 1 /2

No.	Drill Site	Drill Point	Locations		Water Depth (m)	Core Bar-rel	Operation(cm		Drilling Length	Core Length (m)	Core Recovery (%)	Sediments (cm)	Rock Type (cm)
			Latitude	Longitude			start	end					
1	BMS01	02SMS12BMS01A	8°49.3451′ N	163°06.6214′ E	1,371	1	0	71	71	70	100	1	crust (5) 、limestone(65)
2		02SMS12BMS01B	8°49.3386′ N	163°06.5895′ E	1,373	1	0	82	82	77	100	5	limestone(77)
3		02SMS12BMS01C	8°49.3377′ N	163°06.5538′ E	1,380	1	0	71	71	67	96	1	crust (5) 、limestone(62)
4	BMS02	02SMS12BMS02A	8°43.2559′ N	163°09.7643′ E	1,169	1	0	31	31	28	90	0	crust (1) 、lapilli tuff (27)
5		02SMS12BMS02B	8°43.2451′ N	163°09.7098′ E	1,160	1	0	41	41	35	85	0	crust (1) 、lapilli tuff (34)
6		02SMS12BMS02C	8°43.2506′ N	163°09.6691′ E	1,144	1	0	28	28	28	100	0	crust (7) 、lapilli tuff (21)
7	BMS03	02SMS12BMS03A	8°44.5963′ N	163°16.2089′ E	1,349	1	0	37	37	29	97	7	nodule (5) 、crust(5)、cal.conglo. (19)
8		02SMS12BMS03B	8°44.5255′ N	163°16.2652′ E	1,359	1	0	30	30	28	93	0	crust (11) 、basalt(17)
9		02SMS12BMS03C	8°44.5500′ N	163°16.2794′ E	1,360	1	0	40	40	33	83	0	crust (9) 、basalt(24)
10	BMS04	02SMS12BMS04A	8°48.4970′ N	163°18.0573′ E	1,379	1	0	31	31	26	84	0	crust (13) 、basalt(13)
11		02SMS12BMS04B	8°48.5043′ N	163°18.0317′ E	1,373	1	0	33	33	30	94	1	crust (8) 、basalt(22)
12		02SMS12BMS04C	8°48.5134′ N	163°18.0073′ E	1,370	1	0	65	65	50	100	15	crust (6) 、basalt(44)
13	BMS05	02SMS12BMS05A	8°50.2635′ N	163°05.8415′ E	1,319	1	0	31	31	28	97	2	crust (10) 、hyaloclastite(18)
14		02SMS12BMS05B	8°50.1290′ N	163°06.0767′ E	1,313	1	0	30	30	28	100	2	crust (8) 、cal.conglo.(20)
15		02SMS12BMS05C	8°50.0170′ N	163°06.3239′ E	1,313	1	0	31	31	18	58	0	crust (12) 、cal.conglo.(6)
16		02SMS12BMS05D	8°49.9302′ N	163°06.5884′ E	1,296	1	0	32	32	25	78	0	crust (5) 、lapilli tuff(20)
17		02SMS12BMS05E	8°49.8299′ N	163°06.8497′ E	1,304	1	0	33	33	31	100	2	crust (8) 、cal.conglo.(23)
18		02SMS12BMS05F	8°49.4182′ N	163°06.8456′ E	1,330	1	0	22	22	18	82	0	crust (11) 、basalt(7)
19	BMS06	02SMS12BMS06A	8°44.3948′ N	163°12.0989′ E	1,150	1	0	22	22	18	100	4	crust (6) 、lapilli tuff (12)
20		02SMS12BMS06B	8°44.3695′ N	163°12.0764′ E	1,153	1	0	45	45	26	58	0	crust (10) 、lapilli tuff (16)
21		02SMS12BMS06C	8°44.3425′ N	163°12.0617′ E	1,157	1	0	38	38	35	92	0	crust (6) 、lapilli tuff (29)
22	BMS07	02SMS12BMS07A	8°42.8048′ N	163°11.0172′ E	1,376	1	0	29	29	26	100	3	crust (18) 、tuff (8)
23		02SMS12BMS07B	8°42.7985′ N	163°11.0440′ E	1,378	1	0	20	20	19	95	0	crust (10) 、basalt (9)
24		02SMS12BMS07C	8°42.7985′ N	163°11.0440′ E	1,378	1	0	97	97	90	93	0	crust (10) 、basalt (80)
						2	97	155	58	57	98		basalt (57)
						Total			155	147	95		
25		02SMS12BMS07D	8°42.7925′ N	163°11.0720′ E	1,378	1	0	34	34	32	94	0	crust (10) 、basalt (22)
26		02SMS12LC19	8°42.4948′ N	163°07.5098′ E	1,343					150			foraminiferal sand (150)
27		02SMS12LC20	8°42.6895′ N	163°09.8153′ E	1,302					0			
28		02SMS12LC21	8°43.9926′ N	163°11.6109′ E	1,245					0			bit deformed
29		02SMS12LC22	8°44.4110′ N	163°11.2083′ E	1,234					7			foraminiferal sand (5) 、crust (2)
30		02SMS12LC23	8°45.3086′ N	163°11.8053′ E	1,142					0			

Table 3-4-2-2 Sampling Results of MS12 Seamount 2 /2

No.	Drill Site	Drill Point	Locations		Water Depth (m)	Core Bar-rel	Operation(cm		Drilling Length	Core Length (m)	Core Recovery (%)	Sediments (cm)	Rock Type (cm)
			Latitude	Longitude			start	end					
31		02SMS12LC24	8°47.2897′ N	163°12.4993′ E	1,093					0			
32		02SMS12LC25	8°46.4033′ N	163°08.8074′ E	1,275					60			foraminiferal sand (60)
33		02SMS12LC26	8°48.0023′ N	163°07.6034′ E	1,266					55			foraminiferal sand (55)
34		02SMS12LC27	8°50.7082′ N	163°05.8100′ E	1,308					50			foraminiferal sand (50)
35		02SMS12LC28	8°47.3039′ N	163°12.5026′ E	1,093					100			foraminiferal sand (100)
36		02SMS12LC29	8°45.4058′ N	163°10.5054′ E	1,208					0			
37		02SMS12LC30	8°48.7493′ N	163°10.2547′ E	1,145					35			foraminiferal sand (35)
38		02SMS12LC31	8°48.0082′ N	163°07.2081′ E	1,292					65			foraminiferal sand (65) 、bit deformed
39		02SMS12LC32	8°48.0037′ N	163°07.1118′ E	1,302					0			bit deformed
40		02SMS12LC33	8°50.3522′ N	163°07.7590′ E	1,257					105			foraminiferal sand (105)
41		02SMS12LC34	8°51.1515′ N	163°09.4137′ E	1,288					5			crust (5) 、bit deformed
42		02SMS12LC35	8°51.4958′ N	163°11.0064′ E	1,311					65			bit deformed
43		02SMS12LC36	8°51.1480′ N	163°14.0086′ E	1,329					0			fragments of Mn oxides、bit deformed
44		02SMS12LC37	8°43.7051′ N	163°09.2730′ E	1,218					0			fragments of Mn oxides、bit deformed
45		02SMS12LC38	8°42.9013′ N	163°08.5087′ E	1,329					0			fragments of Mn oxides、bit deformed
46		02SMS12LC39	8°42.0027′ N	163°08.4060′ E	1,374					0			fragments of Mn oxides、bit deformed
47		02SMS12LC40	8°50.9976′ N	163°05.2162′ E	1,325					0			fragments of Mn oxides、bit deformed
48		02SMS12LC41	8°51.6944′ N	163°03.2094′ E	1,497					0			fragments of Mn oxides、bit deformed
49		02SMS12LC42	8°52.2546′ N	163°01.5112′ E	1,783					0			fragments of Mn oxides、bit deformed

cal.conglo.: calcareous conglomerate

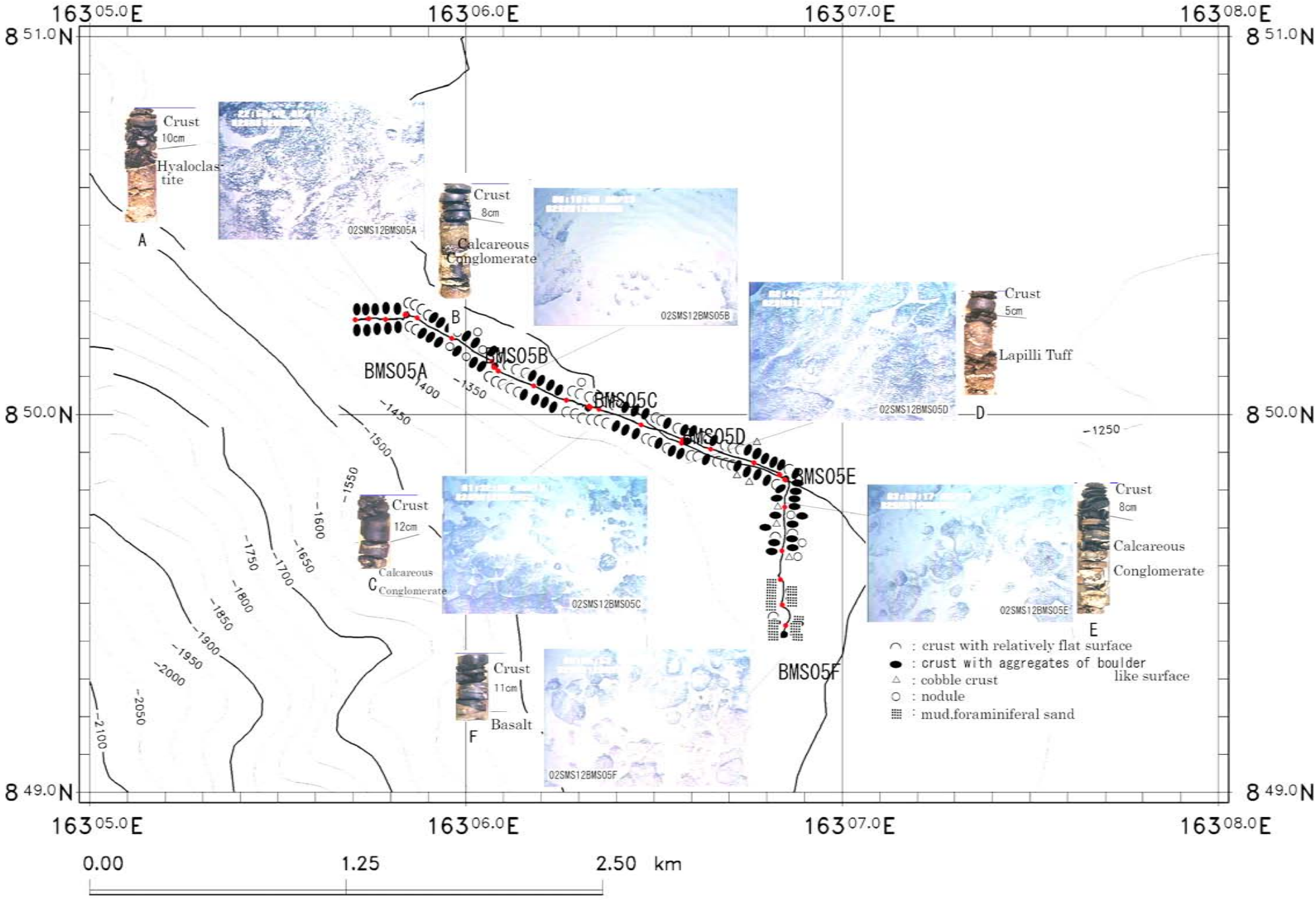


Figure 3-4-2-4 Distribution of Cobalt Crust at BMS05 Site

Descriptions of samples together with circumstances of seafloor at the drilling point are given as below

3 - 4 - 2 - 1 02SMS12BMS01 Site

Drilling Site: At the west side of northwestern part of the summit of the MS12 seamount, dark acoustic zone with 2km width extends between the water depth of 1,300m to 1,500m, suggesting rock exposures. The drilling at BMS01 was done to grasp the distribution of cobalt crust at this area. At the water depth of 1,370m to 1,380m, three drillings, point A (drilling length of 71cm), B (82cm), and C (71cm), were conducted with distance of about 50m from east to west.

Circumstances of Seafloor: The seafloor around the drilling point is a little different from point to point. Around the A point, globular to irregularly swelled crust surface with diameter or size of 20cm to 50cm crops out with exposure rate of 10%, and nodules of diameter of 5cm are scattering over it. The drilling point is on the surface of thin sediments between the exposed cobalt crust. Around the B point, crust exposure was not observed and pebble to cobble size cobalt crust and nodules of diameter of 3cm to 10cm occupy 5% of the surface. The drilling point is on the sediments and nodules of diameter of 3cm to 5cm are seen nearby. Around the point C, cobalt crusts show ripple mark like alignment with exposure rate of 5%. The rate is low but sediments are thin, and the surface is comparatively flat. The drilling point is positioned on the flat cobalt crust with thin sediments.

Cobalt crust: Single layer crust sample of thickness of 45mm at the A point and that of three-layer structure of thickness of 50mm at the C point were collected. At B point, covered by sediments of 5cm thickness, limestone with manganese oxides coating on the surface was collected. There is a possibility that the development of the cobalt crust becomes poor at the place covered by sediments with nodules. The thickness of cobalt crust at this site is, from the simple averaging, 32mm.

Rock sample: Collected samples are all similar from the A point to C. It is pale brown, porous, neritic limestone containing shell fossil and corals, and partly includes grains of manganese oxides.

3 – 4 – 2 – 2　02SMS12BMS02 Site

Drilling Site: At the west of the summit area, the top of the summit stretches out toward southwestern direction, making comparatively flat area of the water depth of 1,200m to 1,400m, and this part shows wide dark tone area in the acoustic intensity image. To understand the distribution of cobalt crust at this part, drilling of BMS02 site at the central part of the dark tone area with the water depth of 1,169m to 1,144m was carried out. Three drillings were conducted from east to west with 60m distances, the point A (drilling length of 31cm), B (41cm), and C (28cm).

Circumstances of seafloor: The seafloor at the drilling points A, B, and C, is similar, and the exposed rock surface shows swelled globular to irregular shaped surface with diameter or length of 20cm to 100cm, but the crust surface is comparatively flat and platy appearance as a whole. The rate of exposure is very high, 80% to 90%. Three drillings were conducted on the comparatively flat, platy crust surface. The C point is positioned on the edge of the exposed crust, and there was a step of 5 cm head on the side of the drilling point.

Cobalt crust: Crust samples were obtained at three points, but those of A and B points are brecciated, and details are not clear. These are all single layer cobalt crust and the thickness of the crust at A and B is assumed to be 15mm, and C is 70mm. Average thickness of three samples is 33mm.

Rock sample: Pale yellowish brown lapilli tuff was collected at all three points.

3 - 4 - 2 - 3　02SMS12BMS03 Site

Drilling Site: At the east of the summit area, acoustic dark tone area is a little narrow, with width of about 1km, and is distributed along the iso-bathymetric line of 1,350m to 1,500m. The BMS03 survey was conducted to grasp the development of cobalt crust at the margin of the southeast of the summit. The BMS03 site has a little wider acoustic dark tone area extending near the water depth of 1,300m. Three drillings were conducted from the A point to B point with 150m distance, and the C point is 50m apart from the B point, drillings of A (drilling length of 37cm), B (30cm), and C were conducted at the water depth of 1,349m to 1,360m.

Circumstances of seafloor: Around the A point, exposure rate is low, 5%, and irregular shaped cobalt crusts of 20cm to 100cm in size are seen. Nodules of diameter of 2cm to 5cm scatter over the sediment and the coverage ratio is about 1 %. The A point is positioned on the sediments near the irregular shape crust of 50cm across. Seafloor around the drilling point B and C shows comparatively flat platy crust surface and partly it shows aggregates of cobble or boulder like surface of swelled globular to ellipsoidal surface of diameter of 20cm to 50cm, and the crust exposure rate is 20% at the B point, and high 80% at the C point. Both B and C drillings were conducted on the flat, platy crust surface.

Cobalt crust: Cobalt crust sample was obtained at all drilling points. At the point A, the surface is sediments of thickness of 7cm and the below is the crust of 35mm thick. At the points B and C, similar, two-layered cobalt crust is observed with thickness of 110mm and 90mm. At the point A where the surface is covered with sediments, the crust is thin, and it is thick at the point B and C where the crust exposes on the surface. Average thickness of the cobalt crust collected from three samples is 78mm.

Rock samples: Calcareous conglomerate was collected at the point A. It includes brown, vitric, sub-angular rock of basalt with the size of 2mm to 30mm, and some of them are coated with manganese oxides. At the points B and C, basalt was obtained. Basalt at B is dark gray, fine basalt without phenocryst, and that at the point C is brown, glassy basalt without phenocryst.

3 - 4 - 2 - 4 02SMS12BMS04 Site

Drilling Site: At the east of the summit area, there develops acoustic dark tone area of width of less than 1km along the bathymetric contour of 1,350m to 1,500m. In order to grasp the development of the cobalt crust in the are, the drilling of BMS04 site was conducted at the water depth of 1,370m to 1,379m. The site is located at the northern extension of the BMS03 site. Three drillings, A (drill length of 31cm), B (33cm), and C (65cm), were conducted with distance of about 50m from east to west alomg WNW direction.

Circumstances of seafloor: Seafloor around the A point shows the cobalt crust surface of aggregates of boulder like, irregular, swelled, globular to irregular shape surface of 20cm to 50cm in size, and the exposure rate is 50%. The drilling

point is on the flat, gently swelled crust surface with diameter of 100cm. Around the B point, the surface is flat consists of platy crust with thin sediments and surface exposure rate is about 20%. The drilling point is on the flat, platy crust surface with thin sediments. Around the C point, the surface is comparatively flat crust covered with thin sediments. The surface partly shows globular swell of diameter of 20cm to 50cm to irregular shape, and the exposure rate is 20%. The drilling point is on the sediments surrounded by the irregular crust of 20cm across.

Cobalt crust: At the points A and B, brecciated cobalt crust was collected and the detail is not clear, but the thickness is respectively, 130mm and 89mm. At the point C, two-layered crust of thickness of 60mm covered by sediments of 15cm was obtained. At the point C where the surface is covered with sediments, the crust is thin compared with A and B where crust surface exposed. The average thickness of the three samples is 90mm.

Rock samples: Basalt was collected at all the points. Basalt of the A and B points is brown to brownish gray, fine grained basalt without phenocryst. Basalt at C is dark gray basalt with micro phenocryst of plagioclase and pyroxene.

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3 - 4 - 2 - 5 02SMS12BMS05 Site

At this site, six holes of drilling with distance of about 500m was conducted to confirm horizontal continuity of the cobalt crust. While moving the vessel to the drilling point, the BMS has been maintained near the sea bottom depth and observation of the seafloor was made by high sensitivity camera installed in BMS with towing the BMS with the speed of 0.5 knot per hour (Figure 3-4-2-4).

Drilling Site: At the northwest part of the summit, dark tone, high acoustic reflection area of 2km width at the water depth of 1,300m to 1,500m is distributed. Maintaining the water depth of 1,300m to 1,350m, six drillings, A (drilling length of 31cm), B (30cm), C (31cm), D (32cm), E (33cm), and F (22cm) were conducted keeping approximately 500m distances between points.

Circumstances of seafloor: The crust was observed over the whole area, There are two types of crust surface were observed, the one is the aggregates of boulder like swelled, globular to ellipsoidal surface and the other is comparatively flat

platy crust. Nodules are seen on the sediments where the exposure rate of the crust is low. The exposure rate from the catch sea bottom point to the drilling point A is high, 60% to 90%, and the aggregates of boulder like crust with swelled, globular to ellipsoidal surface of diameter of 20cm to 100cm is distributed. Around the drilling point A, comparatively flat platy crust crops out with 60% exposure rate, and the point A is positioned on the thin sediments between the exposed crust.

Between the points A and B, the crust of aggregates of boulder like, swelled globular to ellipsoidal surface is dominant partly with comparatively flat platy crust. In the middle of the points A and B, there is a zone with low crust exposure rate of 5% to 20%, and nodule of about 5cm in diameter, are distributed with distribution rate of 10% to 20%. Around the point B, platy crust with comparatively flat surface crops out with the exposure rate of about 30%. The drilling point B is positioned on the surface of thin sediments surrounded by the irregular exposure of platy crust.

Between the points B and C, the surface begins from comparatively flat surface with exposure rate of 50% to 90% and at the middle point, aggregates of boulder like crust dominates. Around the point C, comparatively flat, platy crust crops out with exposure rate of about 30%, and nodules of diameter of about 5cm is scattered. The drill hole C was positioned on the surface of flat platy crust of about 10cm in size.

From the points C to D, flat, platy crust crops out near the C point and apart from this point, both aggregates of boulder like crust and platy crust coexist. The exposure rate is high, showing 50% to 100%, but partly low, less than30%, and nodules are scattering on such surface. The crust surface around the drill hole D is comparatively flat, platy crust with partly irregular part and it crops out with exposure rate of 70%. The drilling was conducted on the margin of the exposure of platy crust of 1m across.

Between the drill points D to E, flat, platy crust dominates and it changes to aggregates of boulder like crust surface toward the point E and the exposure rate decreases. Around the drill point E, it seems to be aggregates of boulder like surface, but globular to irregular shape crust crops out with exposure rate of 20%, covered partly by sediments. The drilling point E is positioned on the thin sediments surrounded by the exposed crust.

Between the drill points E and F, it shows low exposure rate of 5 % to 50%, almost all of the crust is aggregates of boulder like crust, and swelled globular

to ellipsoidal shape crops out on the sediments. At the low exposure rate zone, there develop nodules of diameter of about 5cm. In the zone showing valley topography with east and west direction, the crust is not exposed covered by sediments. Around the drill point F, crust with aggregates of boulder like crust expose showing globular to ellipsoidal swell surface on sediments with exposure rate of 30%. The drill point F is positioned on the thin sediments among crust exposure.

Cobalt crust: Crusts samples were obtained from all of drill points from A to F with 50mm to 120 mm thickness. Among them, core samples at drill point A and E are brecciated to fragments and details are not clear, but the thickness is 100mm and 80mm. Samples of drill point B and F are homogeneous, and thickness is 80mm and 110mm. Samples of drill point C and D have two-layer structure, and the thickness is 120mm and 50mm. At the drill point D, it is little thin, 50mm, but other samples show similar thickness of 80mm to 120mm, and thus thick crust is continuously distributed along the line length of 2.5km at the area. The average thickness of the cobalt crust of the six points is 90mm.

Rock sample: Rock samples at the points are, hyaroclastite, calcareous conglomerate, lapilli tuff, and basalt. Hyaroclastite was collected at the drill point A. It shows grayish brown, and composed of aggregate of glassy volcanic rocks of sizes of 1 cm to 2cm, and includes fine grained manganese oxides. Calcareous conglomerates are collected from the drill points B, C, and E. They are composed of white, foraminifer shell bearing calcareous matrix and vitric basalt or lapilli tuff of grain sizes of 2cm to several tens of mm, and they are coated with manganese oxides. The lapilli tuff collected at the drill point D shows dark gray tuffaceous matrix and vitric volcanic grains of 2mm to 5mm in size. Basalt sample at the drill point F is brownish gray, fine texture basalt and phenocryst is not observed.

3 - 4 - 2 - 6 02SMS12BMS06 Site

Drilling Site: At the flat area of the south of the summit, there is dome like upheaval with 4km x 4km extension, rising 100m high from the water depth of 1,200m, and this area shows dark tone in the acoustic image. The drilling of BMS06 site was conducted to confirm the distribution of crust at the area. Drilling of

three holes, A (drilling length of 22cm), B (45cm), and (38cm), were conducted 50m apart along SW direction at water depth of 1,150m to 1,157m.

Circumstances of seafloor: The seafloor around the three drilling points is similar. The surface consists of comparatively flat platy crust with globular to irregular surface of 20cm to 50cm in size, and the exposure rate is 30% to 50%. The point A was conducted on the surface of sediments 10cm apart from platy crust surface. The drilling point B is positioned on the edge of platy crust with about 10 degrees inclined surface. The point C is positioned on the flat platy crust.

Cobalt crust: Crust was collected at three points. At the point A, it is single layer crust with 60mm thickness, and that at B is two-layered crust with thickness of 100mm. The core at the C point is crushed and detail is not clear, but it is the single layer, 60mm thick cobalt crust. The average thickness of crust at this site is 73mm.

Rock Samples: Lapilli tuff was collected at three drill holes. It consists of yellowish brown tuffaceous matrix and brown vitric volcanic grains with 3mm to 10mm in size. The area of dome like topography has possibility to be formed by volcanic activity due to the distribution of pyroclastic rocks, and a caldera like topography is seen from the topographic map of the summit area.

3 -4 - 2 - 7　02SMS12BMS07 Site

Drilling Site: In order to grasp the distribution of cobalt crust in the dark tone area of the acoustic image at the southwestern stretch of the southwest of the summit, the drilling of BMS07 site was conducted. The BMS07 site is located about 2.5km ESE direction from the BMS02 site, and the water depth is deeper than the BMS02 site about 200m. It is located at the eastern edge of the dark tone area in the acoustic image. The drillings A (drill length of 29cm), B (20cm), and D (34cm), was conducted from west to east at the same water depth, 1,380m depth. Adjacent to the drilling point B, another drilling with a little deeper drilling, C (drill length of 155cm) was conducted to grasp the bedrock circumstances.

Circumstances of seafloor: Around the drill hole A point, globular to irregular surface shape crust of 10cm to 50cm in size crops out at exposure rate of 30%, and

pebbly to cobbly crust or nodules of diameter of 2cm to 20cm scatters on the surface of the sediments. The drilling point A is positioned on the sediments surrounded by comparatively flat crust exposure. Around the drilling point B and C, the surface of the cobalt crust shows the appearance of aggregates of boulders of 30cm to 100cm in diameter, but the crust is platy and not so irregular, and shows comparatively flat surface. The rate of the crust exposure is high, 90%. The drilling point B is positioned on flat crust surface, and the point C is positioned on the rill like part between the gently swelled platy crust. Around point D, comparatively flat platy crust crops out covered with thin sediments of the exposure rate of 30%. Exposed crusts show sometimes ripple mark like alignment. The drilling point is positioned on the flat platy crust surface.

Cobalt Crust: Similar cobalt crust samples were obtained from four drill holes with thickness of 80mm to 100mm. At the drill hole A, the succession is from the top to the lower part, 3cm thick sediments, 80mm thick cobalt crust, and 30mm thick cobble crust. The collected crust samples of the B and C points are brecciated and detail is not clear, but cobalt crust with thickness of 100mm is assumed. The cobalt crust sample of the C point has two-layer structure. The average thickness of the cobalt crust at this site is 93mm.

Rock Samples: Tuff was collected at point A, and basalts from other points. The tuff of A point is pale brown, fine tuff and minute manganese oxides particles align like lamina. Basalts from the drilling points B, C, and D are similar, grayish brown to dark gray color, fine grained, compact basalt and rarely include fine phenocryst of plagioclase and pyroxene. The basalt at the point D shows low alteration.

3 - 4 - 2 - 8 Results of Sampling by LC

The survey by the large gravity corer (LC) was conducted to understand the circumstances of crust exposure and sediments. A total of 24 LC samplings, from LC19 to LC42, were conducted.

(1) Summit area

As the preliminary survey of the sampling by MC and to understand the characteristics of sediments at the summit area covered by light tone in the acoustic

image, the LC survey was conducted at five points, LC24, LC28, LC29, LC30, and LC33. Photographs of the seafloor show that these points are generally covered with sediments and nodules are not distributed. No sample was obtained at the points LC24 and LC29, probably the samples were washed away on occasion of raising the equipments. Foraminiferal sand samples were collected at LC28, LC30, and LC33, with core lengths of 100cm, 35cm, and 105cm, respectively.

(2) Southwest of the summit

In order to confirm the crust exposure at the southwestern part of the area where covered by wide distribution of dark tone in the acoustic image, five LC samplings were conducted, LC19, LC20, LC37, LC38, and LC39. The LC19 and LC20 samplings were conducted at the light tone part of the acoustic image. According to the seafloor photographs, both points are widely covered by sediments. At the LC19 point, foraminiferal sand of 150cm thick was collected. No sample was obtained at the LC20 point.

The survey of LC37, LC38, and LC39 were conducted at dark tone area of the acoustic image. The seafloor photographs show platy crust surface with exposure rate of 70% for LC37, 30% for LC38. At the LC39 point, a whole area is covered with sediments. At these three points, fragments of cobalt crusts were obtained and LC bit was heavily damaged. Crust is assumed to be widely distributed at the area shown by dark tone in the acoustic image at the southwest of the summit.

(3) South of the summit

At the area of dome like topography in the south of the summit where dark tone of the acoustic image is distributed, three LC samplings, LC21, LC22, and LC23 were conducted. The LC21 point is included in the dark tone area in the acoustic image, and the LC22 and LC23 points are positioned at the boundary of dark tone and light tone in the image. Seafloor photographs show the LC22 and LC23 points are covered by sediments as a whole, and at the LC22 point, aggregates of boulder like crust surface exposes with the exposure rate of about 40%. At the LC21and LC22 points tip of LC bit were damaged. No sample was obtained at the LC21 point, but fragments of crust with thickness of more than 20mm was collected at LC22. At the LC23 point, no sample was obtained. Since deformation of the bit was not observed, sediments had washed away on the occasion of raising the equipments.

(4) West of summit

To confirm the exposure of cobalt crust in the dark tone area of the acoustic image along the margin of the summit area, LC sampling was conducted at 4 points LC25, LC26, LC31, and LC32. The LC25 and LC 26 are included in the middle tone area in the acoustic image, and the LC31 point is located at boundary of dark tone and light tone, and the LC32 point is in the dark tone area. Seafloor photographs of LC25, LC26 and LC31 show that all points area covered by sediments, and scatter fragments of cobalt crust but lacks exposure of the crust was observed at LC32.

Foraminiferal sand of core length of 60cm and 55cm were collected at LC25 and LC26, respectively. The thickness of the sediments shown by intermediate tone at this area is assumed to be thicker than these core lengths. At the LC 31, Foraminiferal sand of 65cm thick was collected, but tip of the LC bit was deformed. Crust is expected to exist under thin sediments.

(5) North of the summit

To confirm the expected exposure of crust in the dark tone area of the acoustic image at the margin of the northern part of the summit at water depth of 1,300m to 1,400m, three LC sampling, LC34, LC35, and LC36 were conducted. All three points are located near the boundary of dark tone and intermediate tone in the acoustic image, and are located on the dark side. Seafloor photographs show that LC34 and LC36 points are almost all covered by sediments with a small exposure of crust, but the LC35 point is widely covered by sediments. At LC34, brecciated crust was collected and thickness is assumed to be more than 50mm.

At the LC35 point, foraminiferal sand of core length of 65cm was collected. Since tip of the LC bit was deformed and manganese oxides were attached on it, an existence of crust below the 65 cm thick sediments is expected. At LC 36, since the bit was deformed and a small amount of crust fragments were collected, crust is expected to exist covered by thin sediments. The dark tone area in the acoustic image at the margin of the summit is expected to be covered by cobalt crust of more than 50mm thick.

(6) Northwest of seamount

At the northwest of the seamount, the summit is stretching toward WNW direction, and the WNW extended ridge is formed at the tip. From this summit to the ridge, it forms dark tone area in the acoustic image. Drilling survey was planned to confirm the occurrence of cobalt crust at the area, but it was hampered by bad weather, and, instead, four LC samplings, LC27, LC40, LC41, and LC42 were conducted. The LC27

point is located on the boundary of light tone and dark tone areas in the acoustic image, and the LC40 point is located in the dark tone area in the image. The LC41 and the LC42 points are located at water depth of 1,497m and 1,783m, and in the dark tone area on the ridge extending toward WNW direction. Sea bottom photographs show, the LC27 point is all covered with sediments, and at the points LC40, LC41, and LC 42, platy cobalt crust is distributed with high exposure rate.

Foraminiferal sand of core length of 50cm at the LC27 point and crust fragments at the points LC40, LC41 and LC42 were collected. The ridge extending toward WNW direction from the margin of northwest summit of the seamount is covered by cobalt crust, though the thickness is not clear.

3 - 4 - 3 Geology

Rock samples and type of cobalt crusts obtained by the survey of this year is shown with the results of previous year in Figure 3-4-3-1.

For characteristic rock samples, thin section observation, chemical analysis, age determination and fossil test were conducted and for unconsolidated sediments fossil identification was conducted.

3 - 4 - 3 -1 Outline of Geology

Adding the information of previous year, samples obtained at the MS12 seamount are basalt, pyroclastics (lapilli tuff, tuff, tuff breccia), limestone, calcareous conglomerate and phosphoritic conglomerate, pumice, and foraminiferal sand together with cobalt crust.

Basalts and calcareous conglomerate were collected commonly from the upper part of the area to the margin of the summit, and pyroclastics were sampled at the northwestern and southern parts of the summit. Other than these, pumice samples were obtained everywhere at the upper part of the slope.

The distribution and characteristics of each type of rock are as follows.

Basalt: At the MS12 seamount, basalts were collected at many points from the upper part of the slope to the margin of the summit, and thus basalts are thought to be widely distributed over the seamount. The basalt, when it is slightly oxidized, shows pale brown color. It shows variety of appearances: dark grayish brown to dark gray, compact, fine, porous, and phenocryst is invisible or consists of fine plagioclase and/or pyroxene. At BMS07 site, comparatively fresh basalt with core length over 1m is obtained. At the margin of the northeastern part of the summit, hyaroclastite is collected, and it consists

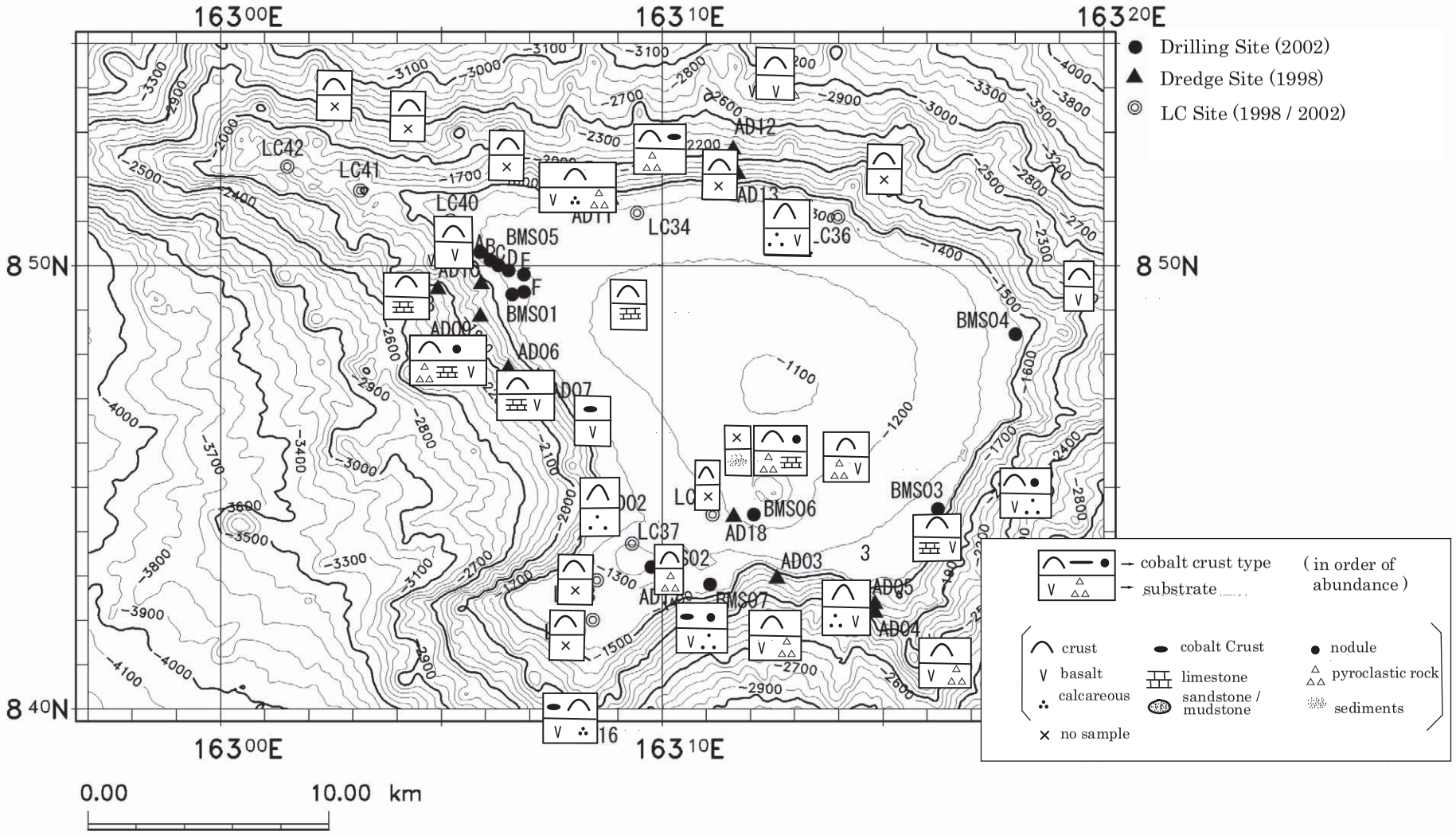


Figure 3-4-3-1 Distributions of Rock and Cobalt Crust in MS12 Seamount

of pale brown to grayish brown vitric basalt fragments. Pebbles of basalt included in calcareous conglomerate are brown, fine, vitric basalt.

Pyroclastics: Pyroclastics are lapilli tuff. tuff breccia and tuff. The their distribution is limited in northeastern part of the seamount and the area summit to the upper slope in the south part of the seamount, thus suggesting volcanic activity associated with eruption took place centering such area.

Limestone: Limestone was sampled at the BMS01 site, and other than that, only small amount of samples were obtained as bedrock of crust or nucleus of nodule. At BMS01 site, it is pale brown, porous, and fossil shell and coral bearing neritic limestone.

Calcareous conglomerate: Calcareous and phosphoritic conglomerate were commonly obtained as well as basalt. The pebbles of theses conglomerates are often covered with manganese oxides, and thus the precipitation of manganese oxides had been started before or during the formation of calcareous matrix.

At the MS12 seamount, there is wide distribution of basalt that forms basal part of the seamount. Pyroclastic rocks are distributed at the south of the summit and northeast of the seamount. The seamount is deposited by limestone, but the distribution is limited and not so thick. Local deposition of neritic limestone suggests that this seamount had been submerged comparatively early stage. From the fact that manganese oxides cover basalt pebbles of calcareous conglomerate and the surface of calcareous conglomerate is covered by cobalt crust, the formation of the cobalt crust had been started before the formation of limestone and had continued afterward.

3 - 4- 3 - 2 Thin Section Observation

For the purpose of clarifying the characteristics of typical rock samples and determine the rock type of unknown rock due to alteration, microscopic observation was conducted. The description of the microscopic observation and the results are shown in Table3-4-3-1 and Appendix 6, and photographs of petrographic microscope are given in Appendix 7.

For the MS12 seamount, petrographic microscope observation of six samples, three basalts (BMS04CTS01, BMS07CTS01, BMS07DTS01), two lapilli tuffs (BMS02CT01, BMS06CTS01), and one hyaloclastite (BMS05ATS01), were carried out.

Three basalt samples were those collected at the margin of the summit area of the

Table 3-4-3-1 Microscopic Observations for Rock Thin section of MS12 Seamount

Sample No.	Occurrence	Rock Type	Microscopic Observations
02SMS12BMS02C TS01 collected at 18-23cm	bedrock of crustクラスト	pale brown, soft rock with black particles..	**hyaloclastite of olivine basalt** : detrital fragments are brecciated scoria of olivine basalt, matrix consists of fine calcite and foraminifera.
02SMS12BMS04C TS01 collected at 50-65cm	basaltic rock covered by crust chemical analysis (BMS04CCA01) Ar Ar age determination (BMS04CAR01)	compact, hard, phenocrysts of olivine and plagioclase observed.	**olivine basalt** : porphyritic, holocrystalline, phenocrysts are plagioclase and olivine, matrix mainly consists of plagioclase associated by clinopyroxene, olivine and opaque minerals.
02SMS12BMS05A TS01 collected at 22-27cm	hyaloclastite covered by crust	brown, soft rock, pale brown veinlets occur.	**hyaloclastite of clinopyroxene olivine basalt** : rock fragments are clinopyroxene olivine basalt and volcanic glass, matrix consists of dendritic clinopyroxene, altered glass and plagioclase, fragments of thermally altered foraminifera ooze are included.
02SMS12BMS06C TS01 collected at 30-35cm	bedrock of crust	pale brown, soft rock.	**hyaloclastite of olivine basalt** : rock fragments of angular basalt and volcanic glass, fragments of thermally altered foraminifera ooze are observed, matrix consists of recrystallized calcite.
02SMS12BMS07C TS01 collected at 97-107cm	basalt covered by crust chemical analysis (BMS07CCA01)	dark gray, compact, hard, phenocrysts of olive and plagioclase are observed.	**olivine clinopyroxene basalt** : porphyritic, groundmass shows flow structure, phenocrysts are plagioclase, olivine, clinopyroxene, groundmass mainly consists of plagioclase associated by olivine, glass, clinopyroxene, opaque minerals.
02SMS12BMS07D TS01 collected at 20-30cm	basalt covered by basalt chemical analysis (BMS07DCA01) Ar-Ar age determination (BMS07DAR01)	dark gray, compact, phenocrysts of olivine and plagioclase are observed.	**olivine clinopyroxene basalt** : porphyritic texture, phenocrysts are plagioclase, olivine and plagioclase, groundmass mainly consists of plagioclase associated by olivine, clinopyroxene, opaque minerals.

eastern (BMS04 point) and the southern part (BMS07 point) of the seamount, and they show dark brown to grayish brown color and comparatively fresh basalts. According to the microscopic observation, basalt from the BMS04 and BMS07 points are similar, the former is olivine basalt containing plagioclase and olivine as phenocryst, and the latter is olivine-clinopyroxene basalt containing plagioclase, olivine and clinopyroxene as phenocryst. Three samples show intergranular texture and groundmass is mainly composed by plagioclase, accompanied by clinopyroxene and olivine. The extent of alteration is, weak for BMS04CTS01 and BMS07CTS01 sample, and a bit strong for BMS07DTS01 sample.

Lapilli tuff is collected from the BMS02 and BMS06 sites of the southern part of the summit, and consists of pale brown matrix containing volcanic fragments of 2mm to 10mm across. Under the microscope, both are similar rock containing brecciated basalt and fragments of volcanic glass in the matrix of calcite and foraminiferal limestone. It is assumed to be hyaloclastite formed by the intrusion of basaltic magma into foraminiferal ooze.

Hyaloclastite is collected at the northeast of the summit, and composed of aggregate of brown color, vitric, volcanic breccias. Under the microscope, it consists of brecciated basalt fragments, fragments of volcanic glass, and fragments of clinopyroxene in the matrix of dendritic clinopyroxene and altered volcanic glass.

3 - 4 - 3 - 3 Results of Petrochemical Analysis

Chemical analysis of basalt was conducted to make clear the nature of igneous activity of the formation of the seamount. The applied analytical methods and the limit of detection are shown in Appendix 8. The result of the analysis is given in Table 3-4-3-2. On the basis of analysis, figures such as chondrite normalized pattern, spiderdigram, $MnO \times 10 - TiO_2 - P_2O_5 \times 10$, $Zr/4 - 2Nb - Y$, $Ti/1000 - V$, and $Nb/Zr - Ba/Zr$, were drawn and given in Appendix 9.

Three samples used for chemical analysis (BMS04CCA01, BMS07CCA01, BMS07DCA01), are olivine basalt and olivine-clinopyroxene basalt collected at the eastern part of the summit (BMS04 point) and at the southwestern part of the summit (BMS07 point). Under the microscope observation, the extent of alteration is weak in BMS04CCA01 and BMS07CCA01, and a little strong in BMS04CCA01.

Concerning the majour elements, three samples show high ratio of Fe_2O_3 to FeO, and Fe is oxidized to quite an extent. Moreover, loss of ignition (LOI) is little high showing 2.47% to 3.66%, and generation of clay minerals is assumed due to weak to a little strong alteration. The content of P_2O_5 is 0.43% to 0.60%, a little high, since common

Table 3-4-3-2 Results of Petrochemical Analysis of MS12 Seamount

		02SMS12	02SMS12	02SMS12
		BMS04C CA01	BMS07C CA01	BMS07D CA01
		olivine basalt	olivine clinopyroxene basalt	olivine clinopyroxene basalt
SiO_2	%	49.14	50.75	50.81
TiO_2	%	2.74	1.66	1.65
Al_2O_3	%	15.39	16.58	16.36
Fe_2O_3	%	6.67	7.11	6.12
FeO	%	3.04	1.40	1.88
MnO	%	0.13	0.14	0.10
MgO	%	5.49	4.53	4.69
CaO	%	8.56	6.16	7.58
Na_2O	%	3.76	4.18	4.25
K_2O	%	1.31	2.64	2.26
P_2O_5	%	0.43	0.60	0.51
CO_2	%	0.07	0.07	1.06
H_2O^+	%	1.08	1.78	1.35
H_2O^-	%	0.84	1.07	0.92
LOI	%	2.47	3.25	3.66
TOTAL	%	99.13	98.99	99.87
FeO*	%	9.04	7.80	7.39
Mg#		0.378	0.367	0.388
Rb	ppm	29.1	72.7	64.4
Sr	ppm	538	733	709
Ba	ppm	350	856	798
Zr	ppm	145	244	236
V	ppm	221	95	103
Nb	ppm	35.9	67.5	65.3
Y	ppm	22.8	22.8	22.2
La	ppm	23.90	57.56	52.88
Ce	ppm	49.89	101.90	95.44
Pr	ppm	6.18	10.60	9.93
Nd	ppm	27.38	38.78	36.41
Sm	ppm	6.42	6.47	6.16
Eu	ppm	2.48	2.36	2.26
Gd	ppm	5.89	5.07	4.90
Tb	ppm	1.00	0.85	0.87
Dy	ppm	4.71	4.41	4.39
Ho	ppm	0.77	0.76	0.73
Er	ppm	2.02	2.08	2.02
Tm	ppm	0.24	0.27	0.27
Yb	ppm	1.48	1.63	1.68
Lu	ppm	0.19	0.24	0.22

basalt has less than 0.5%. The content of CO_2 of the BMS07DCA01 sample shows 1.06%, suggesting the generation of carbonate minerals, however, the extent of alteration and phosphorization is low compared with the samples of the MS01 seamount. The three samples show similar major elements composition similar to common basalt: SiO2 is 49.14% to 50.81%, MgO is 4.53% to 5.49%, MgO/MgO +FeO* is 0.367 to 0.388. The contents of Na_2O + K_2O and T_2O, are high, 5.07% to 6.82% and 1.65% to 2.74%, respectively, and show characteristic of alkaline rock, thus these three samples are classified as alkali basalt from major element chemistry. In the figure of chondrite normalized diagram (Appendix 9, Figure 1), La is 70 to 170 times chondrite, and Lu is 5 to 7 times chondrite, and three samples show "sharply right hand inclined" pattern, characteristic pattern of alkaline rock, and they show similar pattern of alkaline basalt of the seamount of the Marshall Islands reported by Davis et al (1989).

In the Spidergram (Appendix 9, Figure 2), three samples show similar pattern, such elements as K, Rb, Ba, Nb are several tens of times to one hundred times higher than those of mid ocean ridge basalt (MORB), and the pattern is similar to alkaline rock or alkali basalt of the oceanic islands.

Rock discrimination diagram was drawn using trace elements, which are thought to be resistive to alteration. Three samples of the MS12 seamount are, as shown in the $MnO\times10-TiO_2-P_2O_5\times10$ diagram(Appendix 9, Figure 3), and in the Zr/4－2Nb－Y diagram(Appendix 9, Figure 4), all are plotted in the domain of oceanic island alkaline basalt. In the Ti/1000－V diagram (Appendix 9, Figure 5), they are plotted outside the oceanic island alkaline basalt domain, but they show similar high Ti/V ratios to that of oceanic island alkaline basalt.

The ratio of incompatible elements is known to originate the composition of mantle of magma generation, and basalts in the SOPITA (South Pacific Isotopic and Thermal Anomaly) region where the seamounts including those of this area had been formed, are mostly plotted in the rage of 4 to 10 in Ba/Nb ratio (Davis et al, 1989, Christie et al., 1995, Appendix 9, Figure 6). Three samples obtained from the MS12 seamount show the Ba/ Nb ratio of range of 10 to 13, and it has similar Ba/Nb ratio to the basalts of the SOPTIA region.

3 - 4 - 3 - 4　Age Determination

For the two samples, BMS04CAR01 (olivine basalt) and BMS07DAR01 (olivine-clinopyroxene basalt), which show comparatively low alteration among other basalt samples, age determination by the Ar-Ar method was conducted. The samples are obtained in the eastern part and southwestern part of the summit.

On the BMS04CAR01, the plateau age was not obtained, but the isochrone age of 99.68±1.46Ma from the isochrone diagram was obtained. But the initial $^{40}Ar/^{36}Ar$ is 906±162.6, greatly differs from the ratio of that of atmosphere (295.5). For this, the reliability of the obtained age seems low. This is due to the alteration of the rock.

On the BMS07DAR01, the age of 110.0±1.0Ma was obtained from the increment heating age spectra diagram, and similar plateau age of 110.05±0.51Ma was obtained. However, as ^{39}Ar plateau exceeding 50% was not recognized, the reliability of the obtained age is a little low. The reason for this slightly low reliability is that the mineral phase had not been kept as the closed system due to alteration or the intrusion of secondary veins.

The results of age determination obtained from the two samples slightly lacks reliability, but the obtained age, 99.68± 1.46Ma and 110.05±0.51 Ma correspond to Gallic Period of Albian Age of Middle Cretaceous. The formation of seamounts and atolls of the Marshall Islands are considered to be separated into two stages, Middle Cretaceous (Aptian to Cenomanian) and Late Cretaceous (Coniacian to Campanian) from Ar-Ar age and the fossil age of neritic limestone (Lincoln et al.1993, Haggerty and Premoli-Silva, 1995). From this result, the basalt of the basement of the MS12 is thought to have formed in Middle Cretaceous (Aptian to Cenomanian).

3 - 4 - 3 - 5 Fossil Test

Using sediments obtained by the LC sampling and sedimentary rocks obtained by the drilling by the BMS, fossil tests were done to make clear the age of sediments and sedimentary rocks and their sedimentary environment. The result of the fossil test of sediments and rock samples are shown in Table 3-4-3-3 and Table 3-4-3-4. The list of yielded fossils and photographs of typical fossils are shown in Appendix 10.

(1) Fossils in sediments

The five samples were tested, three samples from LC19, and two samples from LC33. The LC19 is located at the southwestern part of the summit, covered by light tone area in the acoustic image. At this site, foraminiferal sand of core length of 150cm was collected, and three samples in the core correspond to, 0 to 5cm (FS01), 40cm to 45cm (FS02), and 125cm to 130cm (FS03). The LC33 is located at the northwestern part of the summit, and included in the light tone area in the acoustic image. From the core length of 105cm of foraminiferal sand, two samples, correspond to depths of 15cm to 20cm (FS01) and 100cm to 105cm (FS02), were examined.

The test results of three samples of the LC19, from the analysis of foraminifer and

Table 3-4-3-3 Results of Fossil Test of Sediments of MS12 Seamount

Site	Depth (m)	Sample No.	Sampling Depth (cm)	Type of Sample	Age Foraminifera	Age Nannofossil	Foraminifera	Nannofossil
02SMS12 LC19	1,343	FS01	0-5	foraminiferal Sand	late Pleistocene (0－0.12Ma)	late Pleistocene (0－0.16Ma)	FS01 includes *Globigerina rubescens* (pink) and *Bolliella calida* and G. ruber (pink) was not found. Geological age of FS01 is late Pleistocene (0.12Ma). In FS02 and FS03, *G. truncatulinoides* was not found and occurrences of G. *fistulosus*, *G. extremus and G. altispira* suggest geological age of Pliocene. No existence of *Sphaeroidinellopsis seminulina* corresponds to geological age of late Pliocene (3.09～3.12Ma).	Occurrence of *Emiliania huxleyi* and no existence of *Helicosphaera inversa* suggest fossil zone of NN21 corresponds to younger than Standard Horizon1, 0～0.16Ma.
		FS02	40-45	foraminiferal Sand	late Pliocene (3.09－3.12Ma)	late Pliocene (2.78－3.85Ma)		FS02 includes late Pliocene fossils, *Discoaster brouweri* (Horizon 13), *D. pentaradiatus* (Horizon 16), *D. surculus* (Horizon 17), *D. tamalis* (Horizon 18) and *Reticulofenestra ampla* (Horizon 19). Geological age is late Pliocene corresponding to fossil zone of lower NN16 (2.78～3.85Ma).
		FS03	125-130	foraminiferal Sand	late Pliocene (3.09－3.12Ma)	late Pliocene (2.78－3.85Ma)		FS02 includes late Pliocene fossils, *Discoaster brouweri* (Horizon 13), *D. pentaradiatus* (Horizon 16), *D. surculus* (Horizon 17), *D. tamalis* (Horizon 18) and *Reticulofenestra ampla* (Horizon 19). Geological age is late Pliocene corresponding to fossil zone of lower NN16 (2.78～3.85Ma).
02SMS12 LC33	1,257	FS01	15-20	foraminiferal Sand	late Pleistocene (0.12－0.22Ma)	late Pleistocene (0－0.16Ma)	FS01 and FS02 include *G. truncatulinoides* of Pleistocene. Occurrences of *B. calida* and *G. ruber* (pink) in FS01 suggest geological age of late Pleistocene (0.12～0.22Ma). *G. tosaensis* was not found in FS02 and geological age for FS02 is middle Pleistocene (0.22～0.65Ma).	Occurrence of *Emiliania huxleyi* and no existence of *Helicosphaera inversa* correspond to fossil zone of NN21, younger than Horizon 1, 0-0.16Ma.
		FS02	100-105	foraminiferal Sand	middle Pleistocene (022－0.65Ma)	late Pleistocene (0.16－0.25Ma)		Occurrences of *Emiliania huxleyi* and *Helicosphaera inversa* correspond to fossil zone of NN21. *Helicosphaera inversa* belongs to Horizon1-2 was found and geological age is 0.16～0.25Ma.

Table 3-4-3-4 Results of Fossil Test of Rocks of MS12 Seamount

Site	Depth (m)	Sample No.	Sampling Depth (cm)	Topographic Division	Type of Sample	Rock Name	Remarks	Geological Age	
								neritic	pelagic
02SMS12 BMS01A	1,371	FR01	16-41	NW. Summit Edge	limestone covered by Mn oxides, sandy limestone is attached on lower side.	bioclastic rudstone (lower part) bioclastic packstone (upper part)	Reefal limestone, texture of cements suggests diagenesis by terrestrial water, fossils such as M*ullusca, Echinoidea, Bryozoa, Sorenopora* are found.	Cretaceous ?	—
02SMS12 BMS01C	1,380	FR01	31-68	NW. Summit Edge	limestone covered by Mn oxides.	bioclastic rudstone	Reefal limestone, texture of cements suggests diagenesis by terrestrial water, fossils such as M*ullusca, Echinoidea,* benthic foraminifera*, Sorenopora* are found.	Cretaceous ?	—

calcareous nanno plankton fossil species, are: FS01to be late Pleistocene (0 to 0.12 Ma?) and FS02 and FS03 to be late Pliocene (2.78 Ma to 3.12Ma?). The results of two samples of LC33 are: FS01 to be late Pleistocene (0.12 Ma to 0.16Ma) and FS02 to be late Pleistocene (0.22Ma to 0.25Ma). The assumed age of sediments obtained from calcareous nanno plankton and foraminifer species shows harmonic results and it seems reasonable compared with other samples from other seamounts.

It is assumed from the characteristics of foraminiferal fossil constituent that the sedimentary environment had been sub-tropical geographic province. The samples lack benthonic foraminiferal fossil and for this reason, paleo-depth cannot be specified, and it is 800m to 2,500m. The deposition speed of LC19 and LC33 differs: it is slow on the former, 0.14mm to 2.74mm/1,000years and fast, 8.94mm /1,000year on the latter.

In LC19 sample, slow deposition speed was obtained on FS01 sample of 0.14mm /1,000years and on FS02 sample of 2.74mm /1,000years. As distinguish hiatus, late Pleistocene and late Pliocene, exists between the two samples, there is a possibility that an unconformity exists between them.

(2) Fossil test of rock sample

The sample tested for fossil remains are two samples, BMS01AFR01 and FR02, obtained at the northwestern part of the periphery of the summit. Both samples contain the cobalt crust of 45mm and 50mm in thickness and they are reef limestone containing fossil shells and corals and manganese oxides particles. The results of fossil test are shown in Appendix 10.

The both samples, BMS01AFR01 and FR02, are reef limestone, and yield *microencruster* and pachydont bivalves-fossil, the geologic age is assumed to be Cretaceous Era. Foraminiferal fossils shells are crushed and difficult to determine the deposition age. Two samples encountered diagenesis under terrestrial water.

From the result of fossil test, the geologic history at the MS12 seamount is as follow.

In Cretaceous Era, the seamount had been exposed over the sea surface up to the position near BMS01 site (water depth of 1,380m at present), and the reef had been formed around the seamount and limestone had deposited. After that, the seamount had uplifted at least the BMS01 site had appeared over the sea surface, and then had submerged to the present depth. By the previous survey, foraminiferal fossil containing pelagic limestone of middle Eocene time had been sampled at the AD05 and AD13 of the upper slope, and in middle Eocene time, the area had been put under pelagic environment. Limestones of the AD05 and AD13 are covered with crust, and thus the main stage of the formation of cobalt crust of the seamount had been middle Eocene and

after. According to Watkins et al. (1995), the formation of cobalt crust in this area and the surrounding area is thought to be Eocene to Oligocene.

3 - 4 - 4 Occurrence of Cobalt Crust

At the MS12 seamount, as the survey of 1998, sampling at the eighteen points (AD: 15 sites, LC: 3 sites) was conducted and cobalt crust sample was obtained from thirteen sites. On the basis of this survey, average thickness of the cobalt crust of 24mm, and average Co grade 0.67% were obtained for MS12 seamount.

In the survey of this year, drilling was conducted at 7 sites in the area of gentle slope and expected exposure of cobalt crust, taking into account of easier exploitation in the future. The purpose of the survey is to understand nature of cobalt crust distribution in the summit area and in different water depths and to clarify horizontal continuity and occurrences under sediments coverage.

3 - 4 - 4 - 1 Distribution

(1)Thickness of cobalt crust

The results of the sampling of cobalt crust of this year and the survey of 1998 is given in Table 3-4-4-1 and Table 3-4-4-2 and the distribution of the cobalt crust is shown in Figure 3-4-4-1. The thickness of cobalt crust relative to water depth and thickness of sediments are given in Figure 3-4-4-2 and Figure 3-4-4-3.

The sampling of 1988 was conducted at the north of summit, west of the summit, and upper slope to the marginal area of the south of the summit, and samples such as crust, cobble crust, and small amount of nodules were collected.

The average thickness of cobalt crust at the each sampling site, excluding nodules, is 1mm to 44mm, and two sites (AD06, AD09), where the amount of collected sample was small, are excluded the average thickness is calculated to be 24mm. The difference of average thickness of the cobalt crust between the summit area of water depth shallower than 1,400m and the slope with the water depth deeper than 1,400m is not significant, and the average thickness is 28mm at the summit area and 23mm at the slope.

In the survey of this year, a total of 25 drillings at the seven sites of the summit area of water depth shallower than 1,400m was conducted. The thickness of cobalt crust at each drilling points show wide range from 0 to 130mm, and average thickness is 74mm. The variation of thickness of cobalt crust at each drilling point of the same site is, comparatively small at the BMS05, BMS06 and BMS07 sites but large at the BMS01, BMS02, BMS03 and BMS04 sites

Table 3-4-4-1 Cobalt Crust Samples Colleceted in Previous Year in MS12 Seamount

No.	Sampling No.	Depth (m)	Topographic Division	Cobalt Crust Type	Crust			Cobble Crust			Total		
					Amount (kg)	Max. (mm)	Min. (mm)	Amount (kg)	Max. (mm)	Min. (mm)	Amount (kg)	Max. (mm)	Min. (mm)
1	98SMS12LC01	4,528	E.foot	nodule									
2	98SMS12AD02	1,554	W.upper slop	crust、crust fragments	79.13	40	23				79.13	40	23
3	98SMS12AD03	1,555	S.upper slop	crust	4.38	55	28				4.38	55	28
4	98SMS12AD04	1,974	S.upper slop	crust	3.42	47	10				3.42	47	10
5	98SMS12AD05	1,719	S.upper slop	crust	5.64	85	9				5.64	85	9
6	98SMS12AD06	1,689	W.uuper slop	crust fragment	0.09	10	6				0.09	10	6
7	98SMS12AD07	1,448	W.uuper slop	cobble crust				194.80	140	44	194.80	140	44
8	98SMS12AD08	2,060	W.uuper slop	crust、crust fragments	17.88	96	34				17.88	96	34
9	98SMS12AD09	1,796	W.uuper slop	ノジュール、crust fragment	0.13	3	1				0.13	3	1
10	98SMS12AD10	1,499	W.uuper slop	crust	1.02	62	19				1.02	62	19
11	98SMS12AD11	1,342	N.summit edge	crust、cobble crust	4.94	60	47	1.70	32	28	6.64	60	39
12	98SMS12AD12	1,983	N.upper slop	crust、crust fargment	1.20	21	10				1.20	21	10
13	98SMS12AD13	1,716	N.upper slop	crust	26.95	53	20				26.95	53	20
14	98SMS12LC14	1,130	N.summit										
15	98SMS12LC15	1,372	E.summit edge										
16	98SMS12AD16	2,268	S.middle slop	crust、cobble crust	55.00	75	32	12.70	90	28	67.70	90	31
17	98SMS12AD17	1,273	S.middle slop	cobble crust、nodule				117.40	95	32	117.40	95	32
18	98SMS12AD18	1,157	summit center	nodule、crust	0.28	27	18				0.28	27	14
					Max.	96	47	Max.	140	44	Max.	140	44
					Ave.	56	23	Ave.	89	33	Ave.	67	24
											Ave.(summit)		28
											Ave.(slop)		23

・AD06 and AD09 were not included for average calculation, because only

Table 3-4-4-2 Sampling Results of Cobalt Crust in MS12 Seamount

No.	Drill Site	Drill Point	Depth (m)	Topographic Division	Sediments (m)	Cobalt Crust	Thickness (mm)	layers	Drill Core	Ave. Thickness (mm)	Bedrock	Seafloor
1	BMS01	02SMS12BMS01A	1,371	NW.summit edge	1	crust	45	1		32	limestone	boulder like surface、ER.10%
2		02SMS12BMS01B	1,373	NW.summit edge	5	coating	0				limestone	cobble crust-nodule occur、ER.5%
3		02SMS12BMS01C	1,380	NW.summit edge	1	crust	50	3			limestone	relatively flat,ER.5%
4	BMS02	02SMS12BMS02A	1,169	SE.summit	0	crust	15	1	crushed	33	lapilli tuff	relatively flat,ER.90%
5		02SMS12BMS02B	1,160	SE.summit	0	crust	15	1	crushed		lapilli tuff	relatively flat,ER.80%
6		02SMS12BMS02C	1,144	SE.summit	0	crust	70	1			lapilli tuff	relatively flat,ER.90%
7	BMS03	02SMS12BMS03A	1,349	SE.summit edge	7	nodule、crust	35	1		78	cal.conglomerate	relatively flat,ER.5%
8		02SMS12BMS03B	1,359	SE.summit edge	0	crust	110	2			basalt	relatively flat,ER.20%
9		02SMS12BMS03C	1,360	SE.summit edge	0	crust	90	2			basalt	relatively flat,ER.80%
10	BMS04	02SMS12BMS04A	1,379	NE.summit edge	0	crust	130		crushed	90	basalt	boulder like surface、ER.50%
11		02SMS12BMS04B	1,373	NE.summit edge	1	crust	80		crushed		basalt	flat、ER.20%
12		02SMS12BMS04C	1,370	NE.summit edge	15	crust	60	2			basalt	relatively flat,ER.20%%
13	BMS05	02SMS12BMS05A	1,319	NW.summit edge	2	crust	100		crushed	90	ﾊｲｱﾛｸﾗｽﾀｲﾄ	relatively flat,ER.60%
14		02SMS12BMS05B	1,313	NW.summit edge	2	crust	80	1			cal.conglomerate	relatively flat,ER.30%
15		02SMS12BMS05C	1,313	NW.summit edge	0	crust	120	2			cal.conglomerate	relatively flat,ER.30%
16		02SMS12BMS05D	1,296	NW.summit edge	0	crust	50	2			lapilli tuff	relatively flat,ER.70%
17		02SMS12BMS05E	1,304	NW.summit edge	2	crust	80		crushed		cal.conglomerate	boulder like surface、ER.20%
18		02SMS12BMS05F	1,330	NW.summit edge	0	crust	110	1			basalt	boulder like surface、ER.30%
19	BMS06	02SMS12BMS06A	1,150	S.summit	4	crust	60	1		73	lapilli tuff	relatively flat,ER.30%
20		02SMS12BMS06B	1,153	S.summit	0	crust	100	2			lapilli tuff	relatively flat,ER.40%
21		02SMS12BMS06C	1,157	S.summit	0	crust	60	1	crushed		lapilli tuff	flat、ER.50%
22	BMS07	02SMS12BMS07A	1,376	S.summit edge	3	crust、cobble crust	80	2		93	tuff	boulder like surface、ER.30%
23		02SMS12BMS07B	1,378	S.summit edge	0	crust	100		crushed		basalt	relatively flat,、ER.90%
24		02SMS12BMS07C	1,378	S.summit edge	0	crust	100		crushed		basalt	relatively flat,、ER.90%
25		02SMS12BMS07D	1,378	S.summit edge	0	crust	100	2			basalt	relatively flat,、ER.30%
						Max.	130			93		
						Min.	0			32		
						Ave.(summit)	74			70		
						S.D.	34			27		

cal.conglomerate: calcareous conglomerate, ER.: exposure r

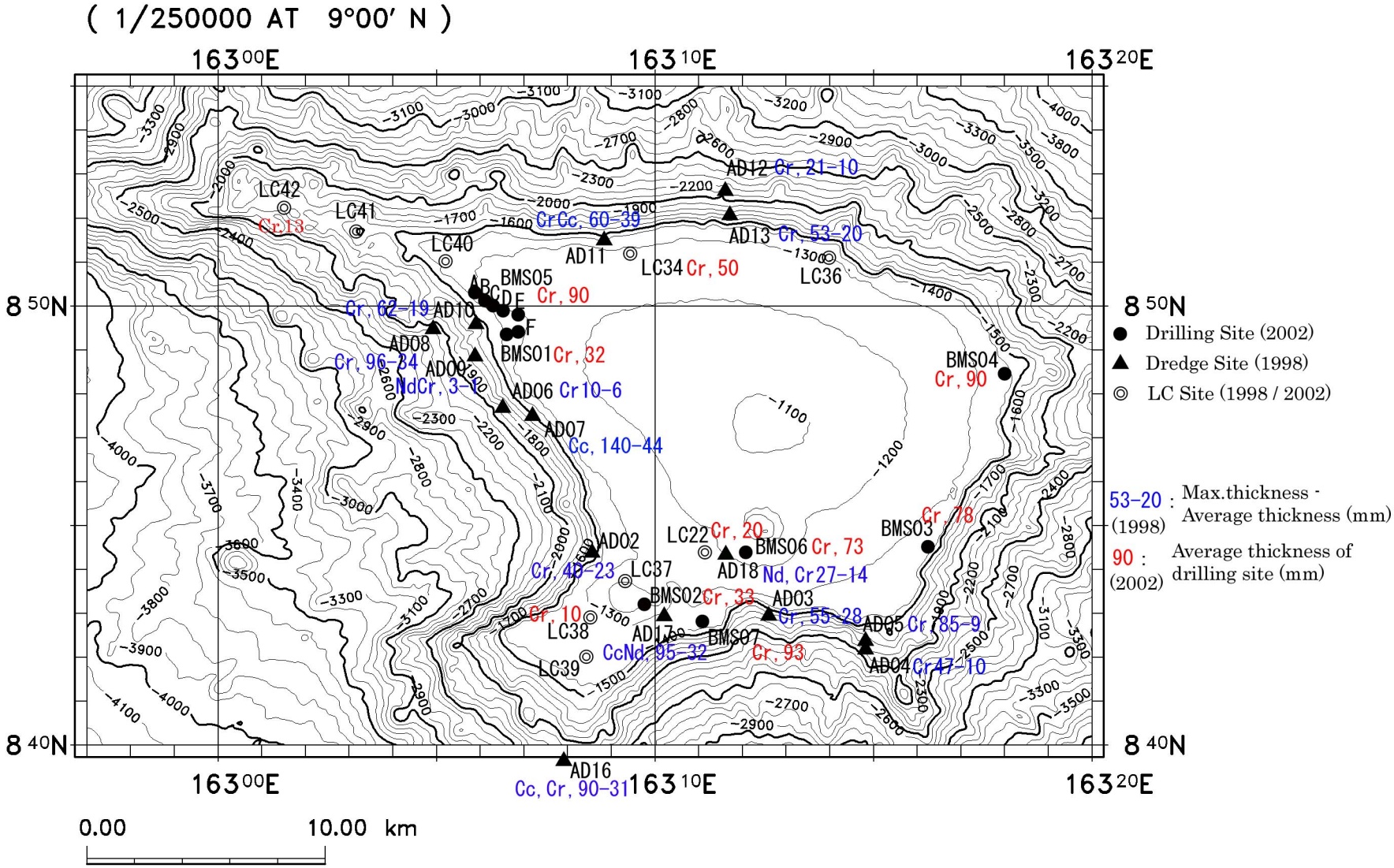


Figure 3-4-4-1 Thickness and Type of Cobalt Crust in MS12 Seamount

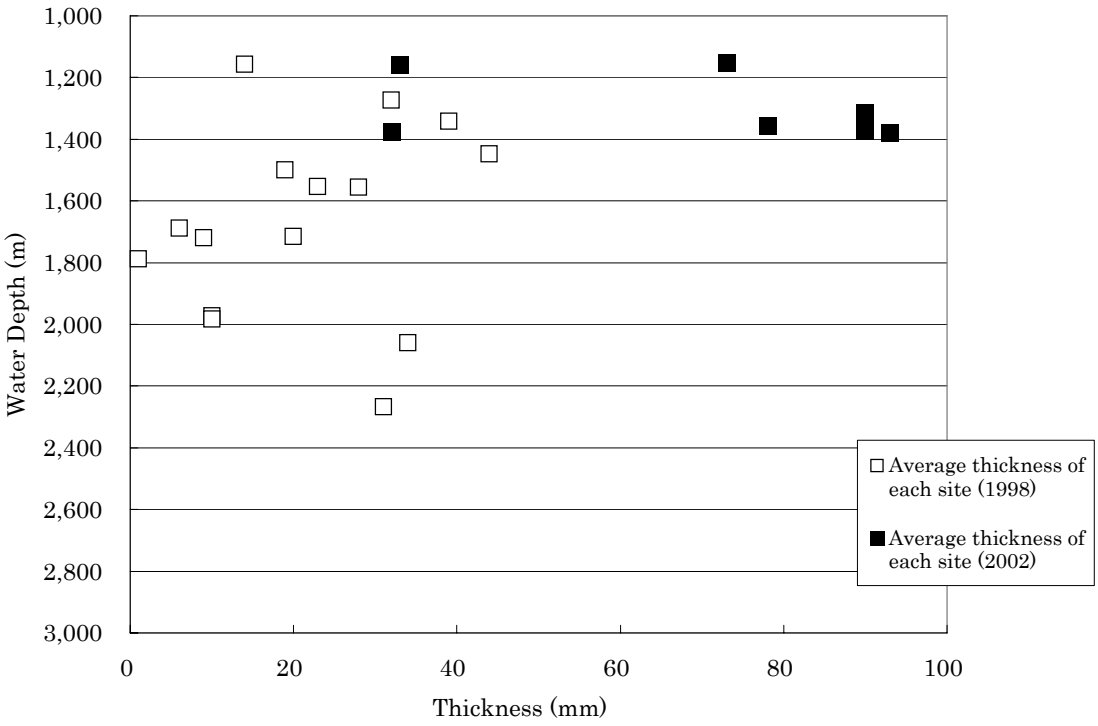


Figure 3-4-4-2 Thickness of Cobalt Crust and Water Depth of MS12 Seamount

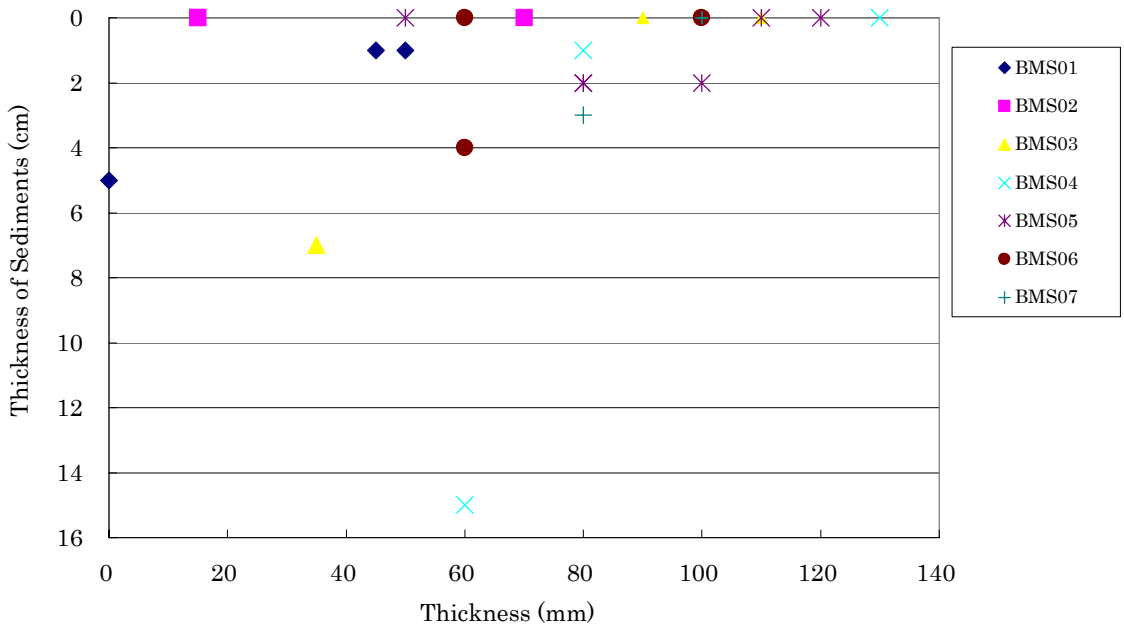


Figure 3-4-4-3 Thicness of Cobalt Crust and Sediments of MS12 Seamount

As is shown in Table 3-4-4-2, the thickness of cobalt crust obtained at the BMS01B, BMS03A, BMS04C points, being covered by unconsolidated sediments of thickness of 5cm, 7cm, 17cm, respectively, is evidently thin compared with other drilling points with exposed crust. It is, also, observed in Figure 3-4-4-3 that cobalt crust with thickness more than 60mm was not obtained at the point being covered by sediments of more than 4cm. At the drilling points where crust is exposed without unconsolidated sediments, the thickness of the cobalt crust varies from 50mm to 130mm, except BMS02A point and B point, and this variation is controlled by factors other than the difference of the thickness of unconsolidated sediments around the drilling points. The thickness of cobalt crust tends to be controlled by the present thickness of unconsolidated sediments as well as the site dependent factors.

The average thickness of cobalt crust at the each site is obtained simply averaging the thickness of three to six drilling points at each site. The average thickness of 7 sites, BMS01 to BMS07, is 37mm to 97mm, and the average of these 7 sites is 70mm. In the 1998 survey average thickness of cobalt crust collected from 3 point of summit area ranges from 14 to 34mm, considerably thin compared with results of this year. The one of the reasons for this seems to be that the calculation of average thickness in the previous survey by dredging is inappropriate. At the AD11 and AD16 sites of the 1998, even samples with maximum thickness of 60mm and 90mm were obtained at each site, the average thickness of each site were 39mm and 32mm. For dredge sampling all types of collected samples, even including incomplete samples, were considered for average calculation. If average thickness of 1998 survey is calculated using the maximum thickness of each site, the average cobalt crust thickness of MS12 seamount becomes 67mm. That value is close to the value of 70mm, obtained by the drilling of this year.

The exposure of cobalt crust at the MS12 seamount shows comparatively flat seafloor for almost all cases and rarely shows aggregates of boulder like rugged irregular surface. The clear relations between the circumstances of exposure and thickness of cobalt crust were not found.

(2) Layer structure

In order to understand the historical sequence of cobalt crust growth, cobalt crust was described subdividing the layers of cobalt crust into seven types on the basis of visual appearance. Each layer of the layer structure is called layer1, layer2, layer3, and so on, from the outer (close to the surface) side to the inner side close to bedrock. The subdivision of the layer is shown in Figure 3-4-4-4.

All most all of the cobalt crust of the MS12 seamount has either single-layer or two

Drilling Site	BMS01			BMS02			BMS03			BMS04			BMS05						BMS06			BMS07			
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	D	E	F	A	B	C	A	B	C	D
Water Depth (m)	1,371	1,373	1,380	1,169	1,160	1,144	1,349	1,359	1,360	1,379	1,373	1,370	1,319	1,313	1,313	1,396	1,304	1,330	1,150	1,153	1,157	1,376	1,378	1,378	1,378
Thickness of Sediments (cm)	1	5	1	0	0	0	7	0	0	0	1	15	2	2	0	0	2	0	4	0	0	3	0	0	0
Type	Crust	g	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust	Crust
Thickness (mm)	45	<1mm	50	15	15	70	35	110	90	130	80	60	100	80	120	50	80	110	60	100	60	80	100	100	100
Bedrock	Limest o-ne	Limest o-ne	Limest o-ne	Lapilli tuff	Lapilli tuff	Lapilli tuff	Calca. Conglo.	Basalt	Basalt	Basalt	Basalt	Basalt	Hyaloc-lastite	Calca. Conglo.	Calca. Conglo.	Lapilli tuff	Calca. Conglo.	Basalt	Lapilli tuff	Lapilli tuff	Lapilli tuff	Tuff	Basalt	Basalt	Basalt
Layers	1		3	1	1	1	1	2	2	unknown	unknown	2	unknown	1	2	2	unknown	1	1	2	unknown	2	unknown	unknown	2

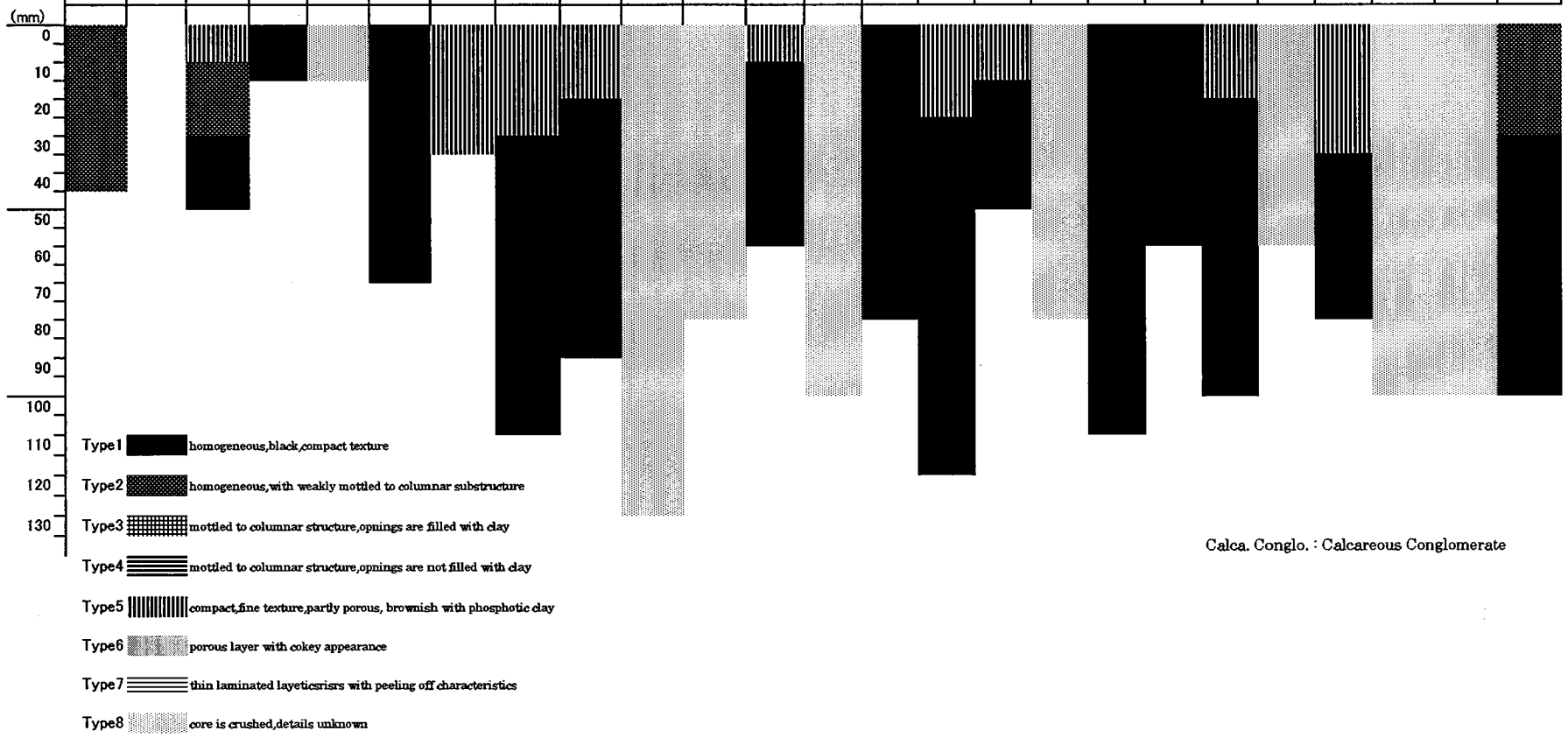


Figure 3-4-4-4 Layer Subdivision of Cobalt Crust of MS12 Seamount

layer structure, and only one case (BMS01C) shows three layer structure. The layer structure shows generally similar pattern, and in case of single layer structure, it shows black, compact Type 1, and in case of two-layer structure, the outermost layer, layer1 is dark brown, fine Type 5, and the layer2 is, black, compact Type 1. At the summit of the MS12 seamount, it is suggested that cobalt crust was formed under similar environment considering from similar layer stricture.

(3) Distribution of cobalt crust

At the summit area of the MS12 seamount, the area of exposed bedrock is distributed from the margin of the summit to the summit of the water depth from 1,200m to 1,400m, and the drilling survey was conducted selecting seven sites within the exposed rock area at the summit. Samples were obtained from all the seven sites and the average thickness of the cobalt crust at each site range from 32mm to 93mm, and average of the seven sites is 70mm. In the survey of 1998, sampling was made at the three sites of the summit area by dredging, and the average thickness of each site was quite thin compared with that of this year, 14mm to 34mm. The average thickness of collected samples obtained by the dredging was thin, but considering the maximum thickness, crust samples of 95mm and 60mm thick were collected. The average thickness of 70mm obtained by the survey of this year seems appropriate.

In order to grasp the relation of the thickness of the cobalt crust with water depth, the drilling survey at the slope was planned, but it was hampered by bad weather. The drilling site of this year is the area from the margin of the summit to the summit, water depth ranging from 1,150m to 1,380m, and the difference of water depth at each site is small. As is shown in Figure 2-4-4-2, the results of the survey of this year do not show any evident relation between thickness of cobalt crust and water depth.

In order to confirm the horizontal succession of the cobalt crust at the exposed rock area, drilling survey at the northeast of the summit was conducted. Six drillings, each of which 500m apart, was carried out along a track line of 3km (Figure 3-4-2-4). The area is partly covered by sediments but, generally, the exposed crust surface, showing comparatively flat surface or rugged crust surface, extends successively. The thickness of cobalt crust is 50mm to 120mm, and average thickness is 90mm. Accordingly, at the area shown by dark tone in the acoustic image, the crust seems to develop successively with uniform thickness to some extent.

To understand the occurrence of cobalt crust under the top sediments, the LC survey at the boundary area of dark tone and light tone in the acoustic image was conducted, but the necessary sample to measure thickness of sediments and to assume

characteristics of cobalt crust beneath it were not obtained. At the points BMS01B, BMS03A, and BMS4C, being covered by sediments of 5cm, 7cm, and 15cm respectively, cobalt crust was obtained, but the thickness is evidently thin compared with the samples obtained by the drilling in exposed area nearby, and thus the development of cobalt crust beneath the sediments becomes poor.

3 - 4 - 4 - 2 Results of Chemical Analysis

For cobalt crust samples obtained by the drilling survey at MS12 seamount, chemical analyses of 34 samples (bulk sample: 32, layer by layer sample: 2) were conducted. A total of 32 elements including 22 elements of Co, Ni, Cu, Mn, Fe, Pb, Zn, Ti, Mo, V, Si, Al, Ca, K, P, Ba, Sr, Pt, LOI, H_2O^+, H_2O^- and 14 rare earth elements, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, were analyzed. The analytical methods and the results are given in Appendix 8 and 11.

(1) Bulk Sample

The statistical values of each elements and major metal elements including Pt of the bulk analysis are shown in Table 3-4-4-3 and Table 3-4-4-4. The histogram of the bulk analysis and the scattergram adding the results of 1998 are given in Figure 3-4-4-5 and Figure 3-4-4-6. Seven samples obtained by the LC sampling at the MS12 seamount were analyzed, but the samples only represent the surface layer of the cobalt crust and thus excluded from calculation of statistical values

The content of Co in the 24 bulk samples shows 0.26% to 0.64%, mainly 0.45% to 0.50%. The content of Ni and Cu are 0.43% to 0.82% and 0.03% to 0.10%, and they show comparatively narrow range, and exhibits normal distribution pattern centering at the average value of 0.58% and 0.05%. Mn and Fe are 17.42% to 25.71% and 6.20% to 14.70%, showing dispersion pattern as a whole. The content of Pt is 0.09ppm to 0.60ppm. The differences of grade among each point in a drill site (e.g. A. B, C) are comparatively small, so that average grade of drilling site (e. g. BMS01) was obtained by averaging grade of each point.

The average chemical content of the cobalt crust at the MS12 seamount, obtained by the survey of this year, is Co 0.46%, Ni 0.57%, Cu 0.05%, Mn 22.22%, Fe 11.41%, and Pt 0.40ppm. Compared with the result of 1998, the content of Co and Fe are low, and there is no marked difference in Ni, Cu, Mn, and Pt. Compared with the average of the Central Pacific crust (Hein et al., 1992), Co and Fe are low and Pt is high.

In the dispersion diagrams, it shows positive correlation for Co-Mn, and Co-Fe, and negative correlation for Co-Cu. There is no marked relation between water depth and

Table 3-4-4-3 Chemical Characteristics of Cobalt Crust of MS12 Seamount

	Co %	Ni %	Cu %	Mn %	Fe %	Mn/Fe	Pb %	Zn %	Ti %	Mo %	V %	Si %	Al %	Ca %	Na %	K %	P %	Ba %	Sr %	Pt ppm
Max.	1.51	1.23	0.19	30.66	17.50	3.40	0.20	0.13	1.29	0.09	0.10	2.43	1.43	17.87	1.90	0.58	6.14	0.40	0.30	0.60
Min.	0.23	0.43	0.03	14.75	6.20	1.44	0.06	0.07	0.36	0.04	0.06	0.56	0.15	2.59	1.19	0.32	0.38	0.16	0.12	0.09
Ave.	0.56	0.61	0.06	23.17	12.05	1.98	0.13	0.09	0.70	0.07	0.08	1.39	0.42	10.57	1.54	0.45	3.31	0.24	0.21	0.39
S.D.	0.27	0.15	0.03	3.33	2.54	0.41	0.03	0.01	0.19	0.01	0.01	0.51	0.25	4.07	0.14	0.06	1.52	0.04	0.05	0.12
C.V.	0.49	0.24	0.55	0.14	0.21	0.21	0.25	0.15	0.28	0.18	0.13	0.36	0.60	0.38	0.09	0.13	0.46	0.19	0.25	0.31

	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	ΣREE ppm
Max.	374	1805	53.0	234.0	43.2	12.7	62.2	9.0	55.3	13.1	40.8	5.8	38.0	6.2	2752.3
Min.	104	424	16.1	72.0	12.9	3.8	18.0	2.5	16.1	3.7	11.7	1.7	11.1	2.0	940.1
Ave.	273	1184	38.7	172.3	30.5	9.0	42.5	6.1	39.3	8.7	27.9	3.8	24.7	4.2	1865.1
S.D.	46	330	6.1	27.0	5.1	1.4	7.0	1.0	6.3	1.6	5.0	0.7	4.6	0.8	383.0
C.V.	0.17	0.28	0.16	0.16	0.17	0.16	0.16	0.17	0.16	0.18	0.18	0.18	0.19	0.19	0.21

N=31
(bulk samples)

Table 3-4-4-4 Grade of Cobalt Crust of MS12 Seamount

	Drill Site	Drill Point	Depth	Thickness (mm)	Co %	Ni %	Cu %	Mn%	Fe %	Mn/Fe	Pt ppm	Ave. Depth (m)	Max. Thickness (mm)	Ave. Thickness (mm)	Ave. Co %	Ave. Ni%	Ave. Cu%	Ave. Mn %	Ave. Fe%	Ave. Fe/Mn	Ave. Pt ppm
1	BMS01	A	1,371	45	0.35	0.55	0.07	20.83	10.60	1.97	0.49	1,376	50	32	0.37	0.56	0.07	20.79	11.45	1.83	0.45
2		C	1,380	50	0.39	0.57	0.07	20.75	12.30	1.69	0.42										
3	BMS02	A	1,169	15	0.60	0.63	0.05	24.31	9.70	2.51	0.60	1,158	70	33	0.49	0.68	0.05	23.38	9.20	2.67	0.43
4		B	1,160	15	0.31	0.82	0.06	21.06	6.20	3.40	0.40										
5		C	1,144	70	0.57	0.60	0.04	24.78	11.70	2.12	0.30										
6	BMS03	A	1,349	45	0.26	0.71	0.10	17.42	9.40	1.85	0.58	1,356	110	78	0.41	0.57	0.07	20.80	11.30	1.84	0.45
7		B	1,359	110	0.46	0.48	0.06	22.07	12.10	1.82	0.39										
8		C	1,360	90	0.51	0.52	0.06	22.92	12.40	1.85	0.37										
9	BMS04	A	1,379	130	0.48	0.45	0.05	23.00	12.20	1.89	0.36	1,374	130	90	0.40	0.46	0.06	20.88	12.70	1.65	0.51
10		B	1,373	80	0.35	0.43	0.06	19.36	12.80	1.51	0.58										
11		C	1,370	60	0.36	0.49	0.08	20.29	13.10	1.55	0.59										
12	BMS05	A	1,319	100	0.48	0.68	0.06	23.69	9.30	2.55	0.32	1,329	120	90	0.46	0.60	0.05	22.43	11.05	2.09	0.35
13		B	1,313	80	0.46	0.53	0.05	22.77	12.40	1.84	0.35										
14		C	1,313	120	0.41	0.61	0.05	21.91	10.00	2.19	0.38										
15		D	1,396	50	0.57	0.70	0.05	25.09	11.00	2.28	0.27										
16		E	1,304	80	0.48	0.47	0.06	21.68	14.70	1.47	0.31										
17		F	1,330	110	0.34	0.60	0.06	19.44	8.90	2.18	0.48										
18	BMS06	A	1,150	60	0.48	0.60	0.04	23.46	12.10	1.94	0.09	1,153	100	73	0.56	0.59	0.04	22.71	12.00	1.91	0.28
19		B	1,153	100	0.64	0.57	0.04	20.75	13.00	1.60	0.41										
20		C	1,157	60	0.57	0.60	0.04	23.93	10.90	2.20	0.34										
21	BMS07	A	1,376	80	0.56	0.54	0.06	23.31	14.60	1.60	0.36	1,378	100	93	0.52	0.56	0.04	24.53	12.40	2.04	0.34
22		B	1,378	100	0.50	0.65	0.03	25.71	9.60	2.68	0.32										
23		C	1,378	100	0.53	0.55	0.04	25.09	12.00	2.09	0.35										
24		D	1,378	100	0.51	0.51	0.05	24.00	13.40	1.79	0.36										
			Samples	24	24	24	24	24	24	24	24		7	7	7	7	7	7	7	7	7
			Max.	130	0.64	0.82	0.10	25.71	14.70	3.40	0.60		130	93	0.56	0.68	0.07	24.53	12.70	2.67	0.51
			Mini.	15	0.26	0.43	0.03	17.42	6.20	1.47	0.09		50	32	0.37	0.46	0.04	20.79	9.20	1.65	0.28
			Ave.	77	0.47	0.58	0.05	22.40	11.43	2.02	0.39		97	70	0.46	0.57	0.05	22.22	11.44	2.00	0.40
			S.D.	31	0.10	0.09	0.01	2.10	1.96	0.44	0.12		28	27	0.07	0.07	0.01	1.46	1.16	0.33	0.08
			C.V.	0.40	0.21	0.16	0.28	0.09	0.17	0.22	0.30		0.29	0.38	0.16	0.12	0.22	0.07	0.10	0.16	0.20
									Results of 1998			Samples	15	15	15	15	15	15	15	15	15
												Ave.	60	22	0.67	0.56	0.04	23.89	14.40	1.71	0.47
									Ave. Central Pacific *			Samples			308	311	265	311	311	311	29
												Ave.			0.79	0.47	0.12	23.00	15.70	1.39	0.24

*Average value of the Central Pacific Crust (Hein et al. 1992)

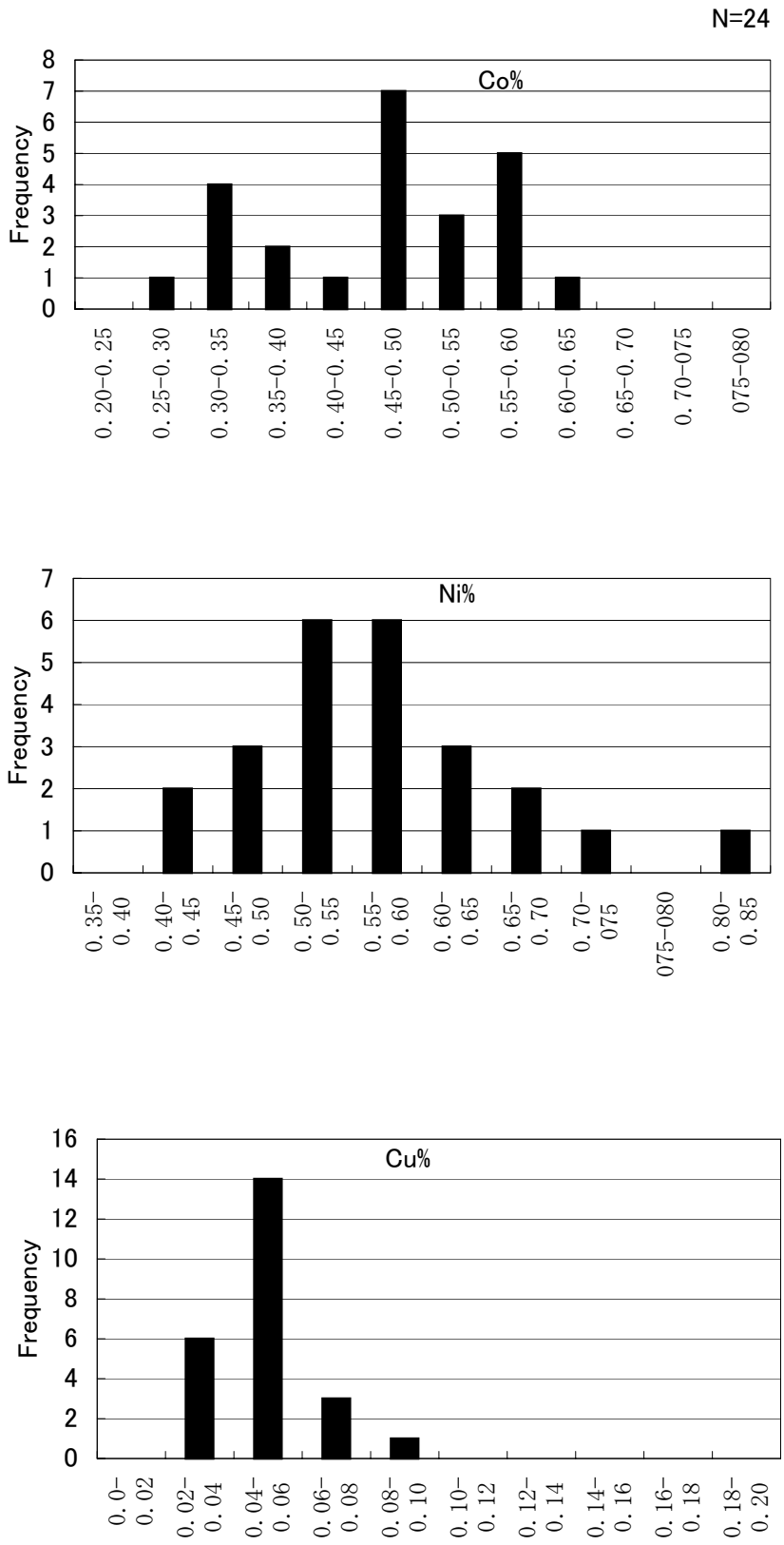


Figure 3-4-4-5 Assay Results Histgram of MS12 Seamount1 (1/2)

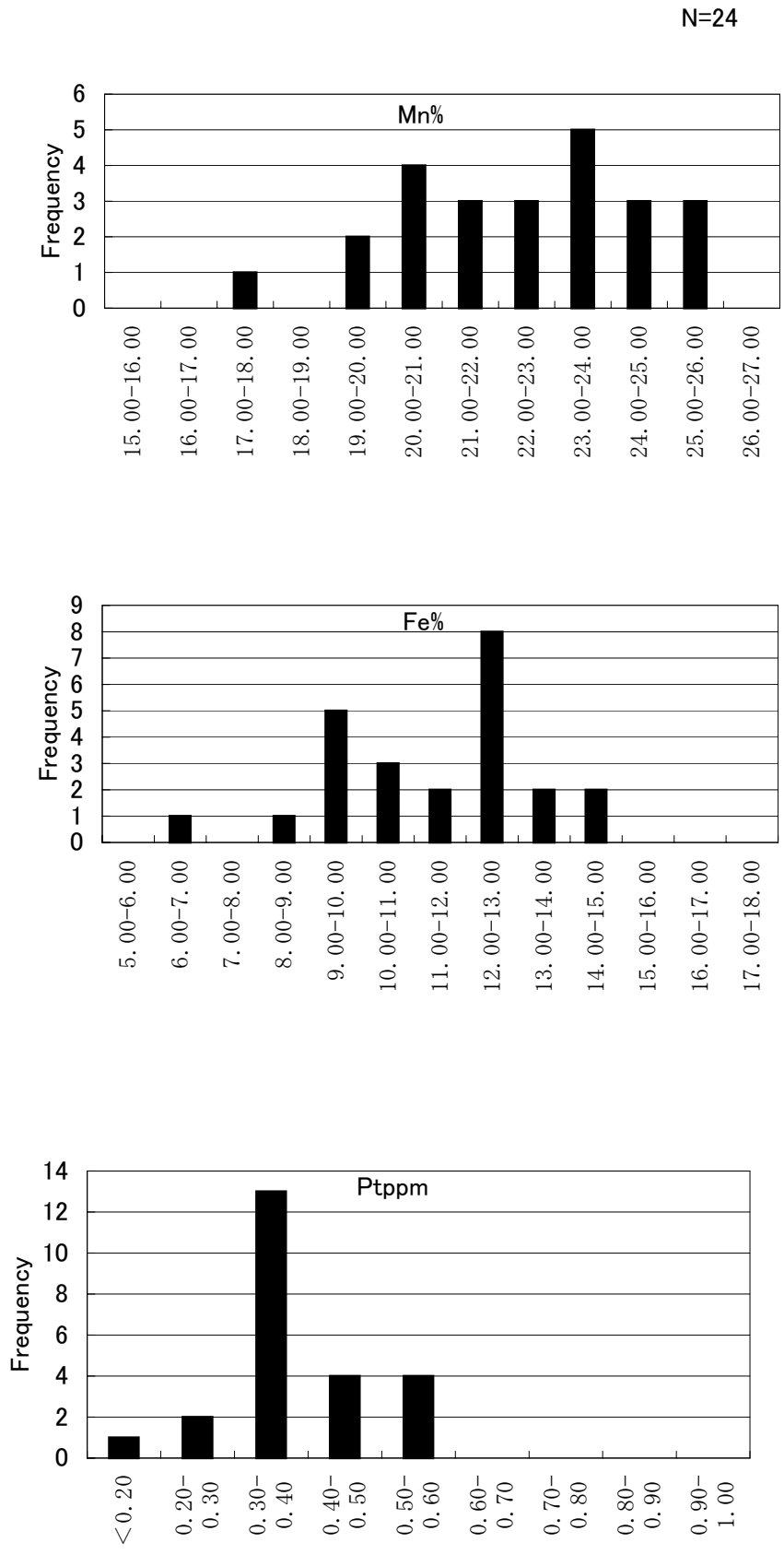


Figure 3-4-4-5 Assay Results Histgram of MS12 Seamount2 (2/2)

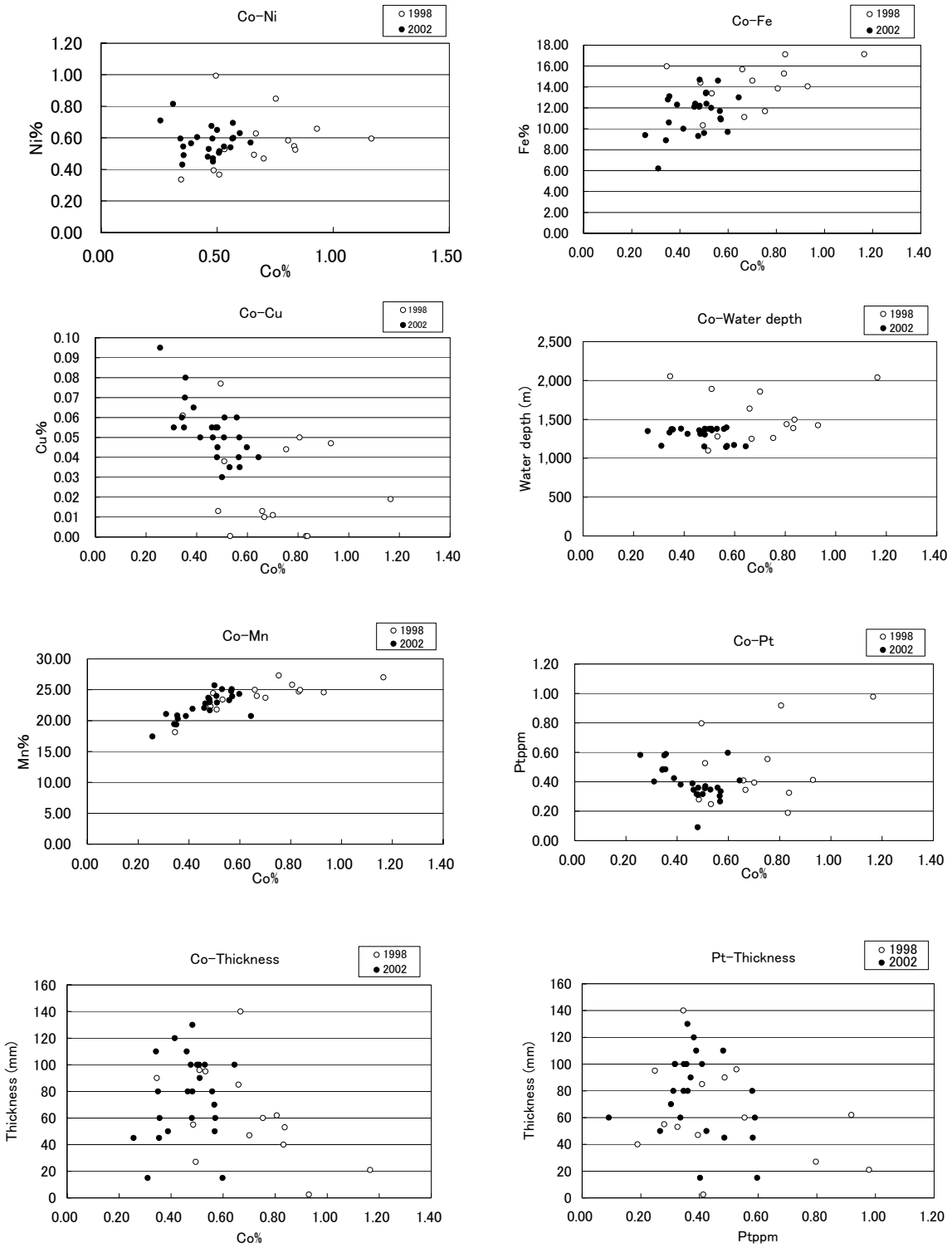


Figure 3-4-4-6 Dispersion Diagram of Assay Results of MS12 Seamount

Co, but there is negative correlation between Co and thickness in the survey result of 1998, and Co grade of more than 0.80% is obtained only from cobalt crust with thickness less than 60mm.

Other than above elements, the average content of metal elements, Pb, Zn, and Mo shows 0.13%, 0.09%, and 0.07%, respectively. The content of Ca and P shows wide range, 2.59% to 17.87% and 0.38% to 6.14%, and the average is high, 10.57% and 3.31%. Both elements show very good correlation.

On the rare earth elements of the bulk sample, the average ΣREE is 1,865ppm, and it has broad range from, 940 ppm to 2,752ppm. This is due to the variation of Ce, from 424ppm to 1,805ppm.

In the North American standard shale normalized diagram, it shows flat pattern, and concentration of 4 to 10 times of shale with positive anomaly of Ce. This pattern is similar to that of hydrogenetic crust of the seamounts in the Pacific region (Usui and Someya, 1997).

(2) Layer-by-layer sample

Only one crust was examined for layer-by-layer. It shows similar tendency with the samples of the MS01 seamount, and the outside layer1 (Co 0.78%) has higher content of Co than layer2 (Co 0.39%). In case of Ca and P, chemical differences are more clear, the contents of Ca and P for the layer1 are Ca 2.82% and P 0.52% but for the layer2, they becomes Ca 12.23%, and P 3.95%. On the LC samples, which seem to represent the outermost layer with high Co. Samples such as LC34, LC36 andLC41 have high Co contents of more than 1.00%.

(3) Grade and thickness

The distribution of grade of the cobalt crust at each sampling site is shown in Figure 3-4-4-7 as well as the thickness of the crust. The thickness of cobalt crust of the 1998 survey, obtained by dredging and the LC sampling, is shown by the maximum thickness of each site.

As the result of the survey of this year, the average grades of the cobalt crust obtained from the seven sites at the summit area by the drilling survey are Co content of 0.37% to 0.56 % and average grade of them is 0.46%. There is no specific relation on the distribution of the grade of Co, and cobalt crust with Co of grade of 0.46% is considered to be widely distributed in the summit area.

The thickness of the cobalt crust of the seven sites at the summit shows wide variation, 32mm to 93mm, and the average thickness of them is 70mm.

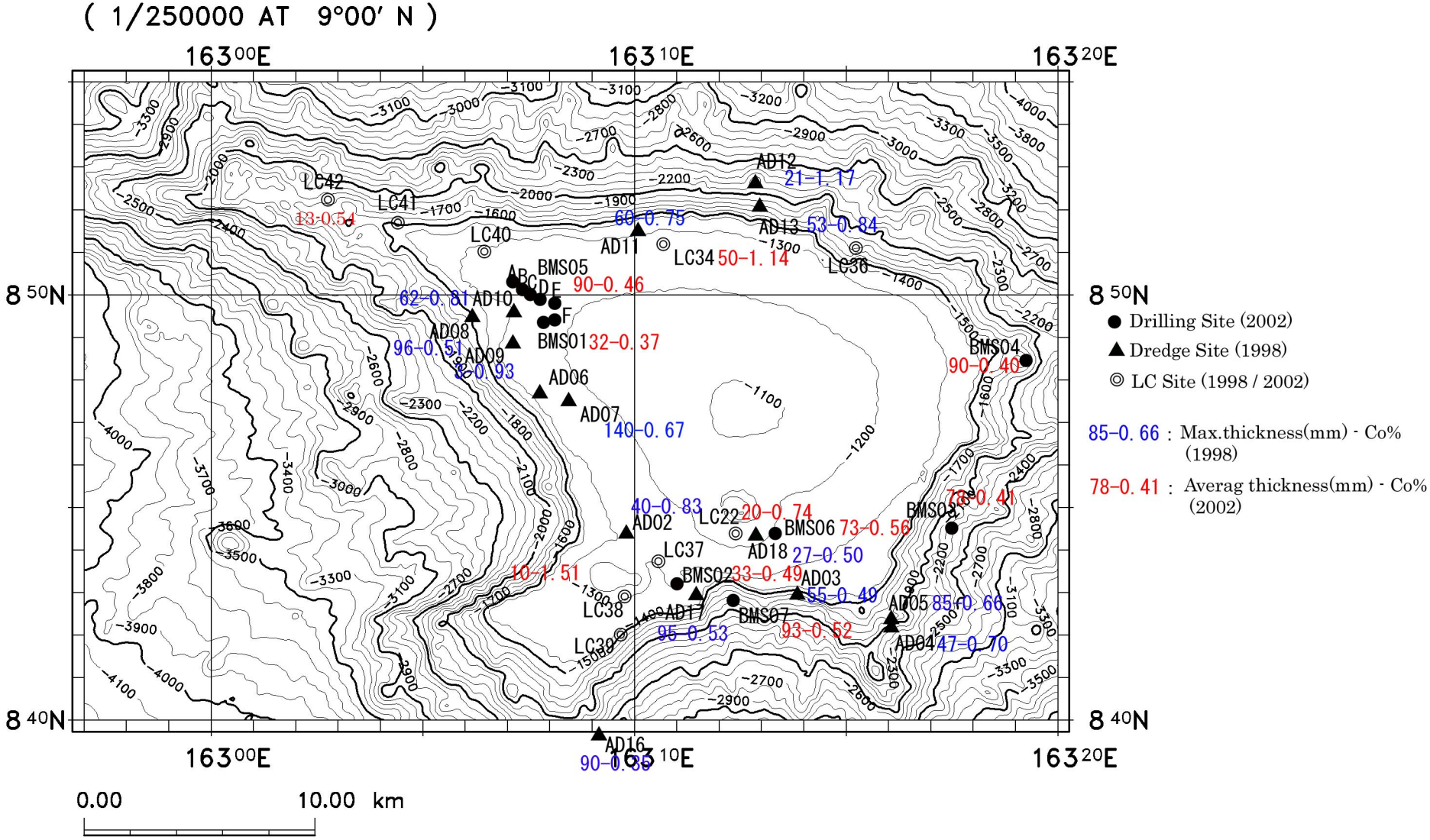


Figure 3-4-4-7 Co Grade and Thickness of Cobalt Crust in MS12 Seamount

As the result of the survey of 1998, the average Co grade of 0.67% was obtained and this is higher than the result of this year. As shown in the layer-by-layer analysis results, the grade of Co of the outermost layer is high. This year survey shows Co grade of 0.78% for the outermost layer of cobalt crust. The average thickness of the cobalt crust of the survey of 1998 is, if we calculate on the basis of the maximum thickness of each site, it becomes 67mm, and this is close to the result of this year, 70mm.

3 - 5 Environmental Survey

3 - 5 - 1 Survey Area

Surveys were conducted in three seamounts of MS01, MS11 and MS12, located in the EEZ of the Marshall Islands.

At the top of MS01, a flat area extends approximately 20 km from west to east, and 15 km from south to north. The water depth there is 1,100 m. A steep slope extends from the top to the foot of the seamount (Figure 3-5-1-1). Samples were collected from the top (MC03 at 1,221 m and MC04 at 1,156 m), and at sites 200 m deeper than there (MC01 at 1,542 m and MC02 at 1,469 m).

At the MS11 seamount, the water depth is approximately 1,500 m at the top, and its area extends 12 km from east to west and 16 km from north to south. Around the top, a gentle slope continues to a 2,000 m depth and then becomes very steep (Figure 3-5-1-2). Samples were collected from the top at two sites (MC03 at 1,549 m and MC04 at 1,513 m), a site 200 m deeper than there (MC02 at 1,749 m) and then an even deeper site at 2,131 m (MC01).

The water depth at the top of the MS12 seamount is approximately 1,000 m, and its area extends 10 km from east to west and 12 km from north to south. Around the top, a gentle slope continues to a 1,500m depth, and then it becomes very steep from that depth to 4,000 m (Figure 3-5-1-3). Samples were collected from three stations, i.e., MC01 at 1,093 m, MC02 at 1,146 m and MC03 at 1,257 m.

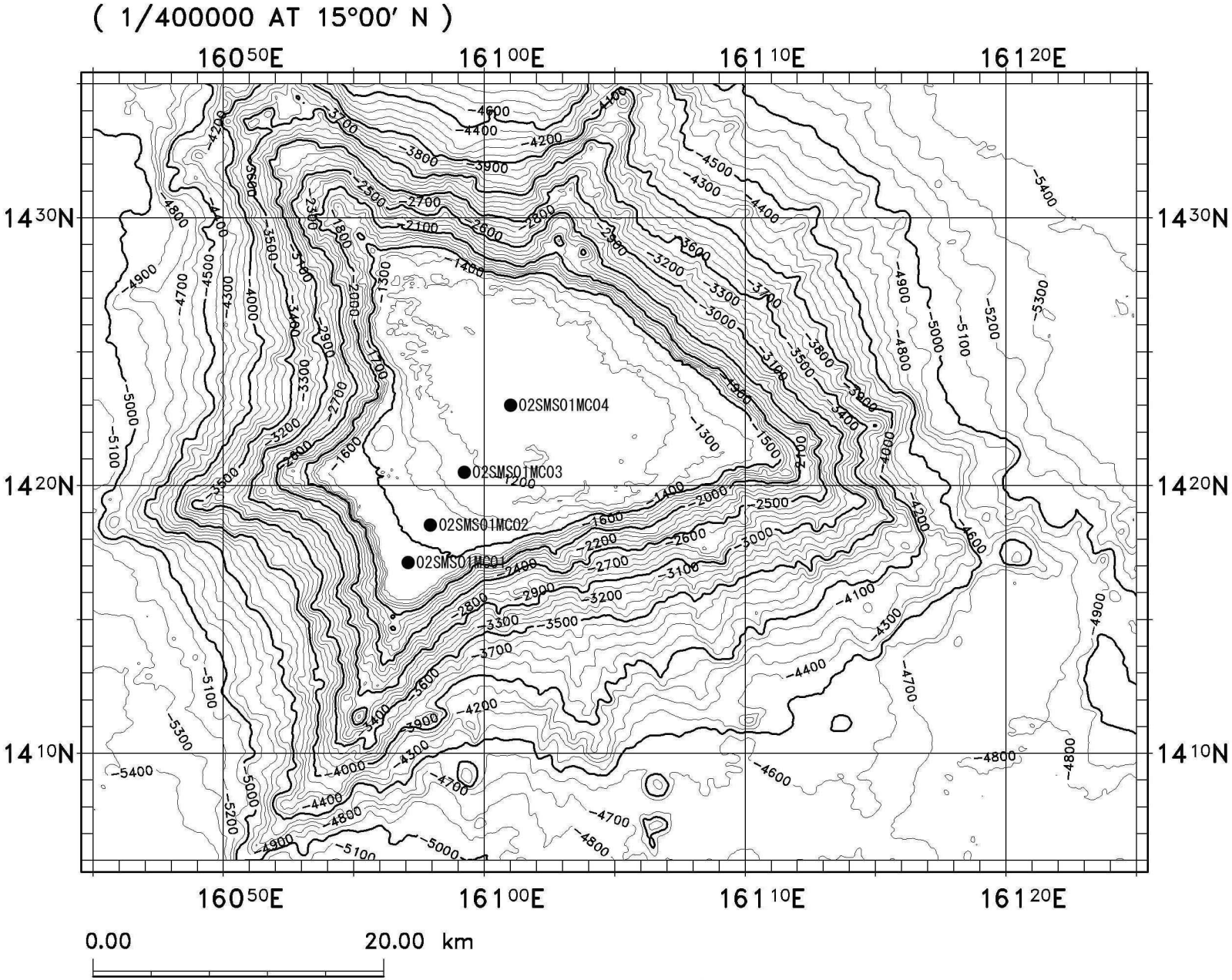


Figure 3-5-1-1 Location Map of Sampling Sites (MS01 Seamount)

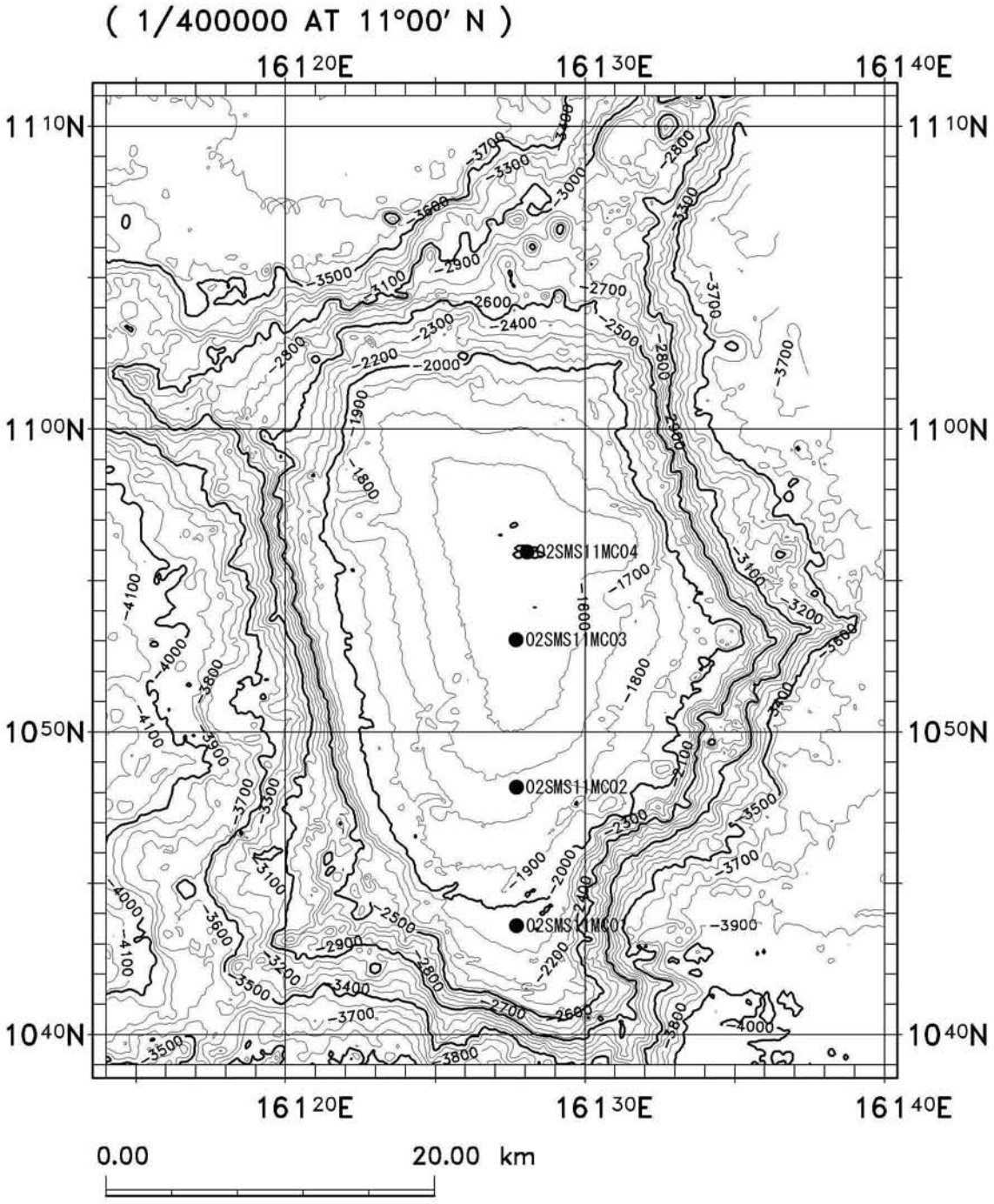


Figure 3-5-1-2 Location Map of Sampling Sites (MS11 Seamount)

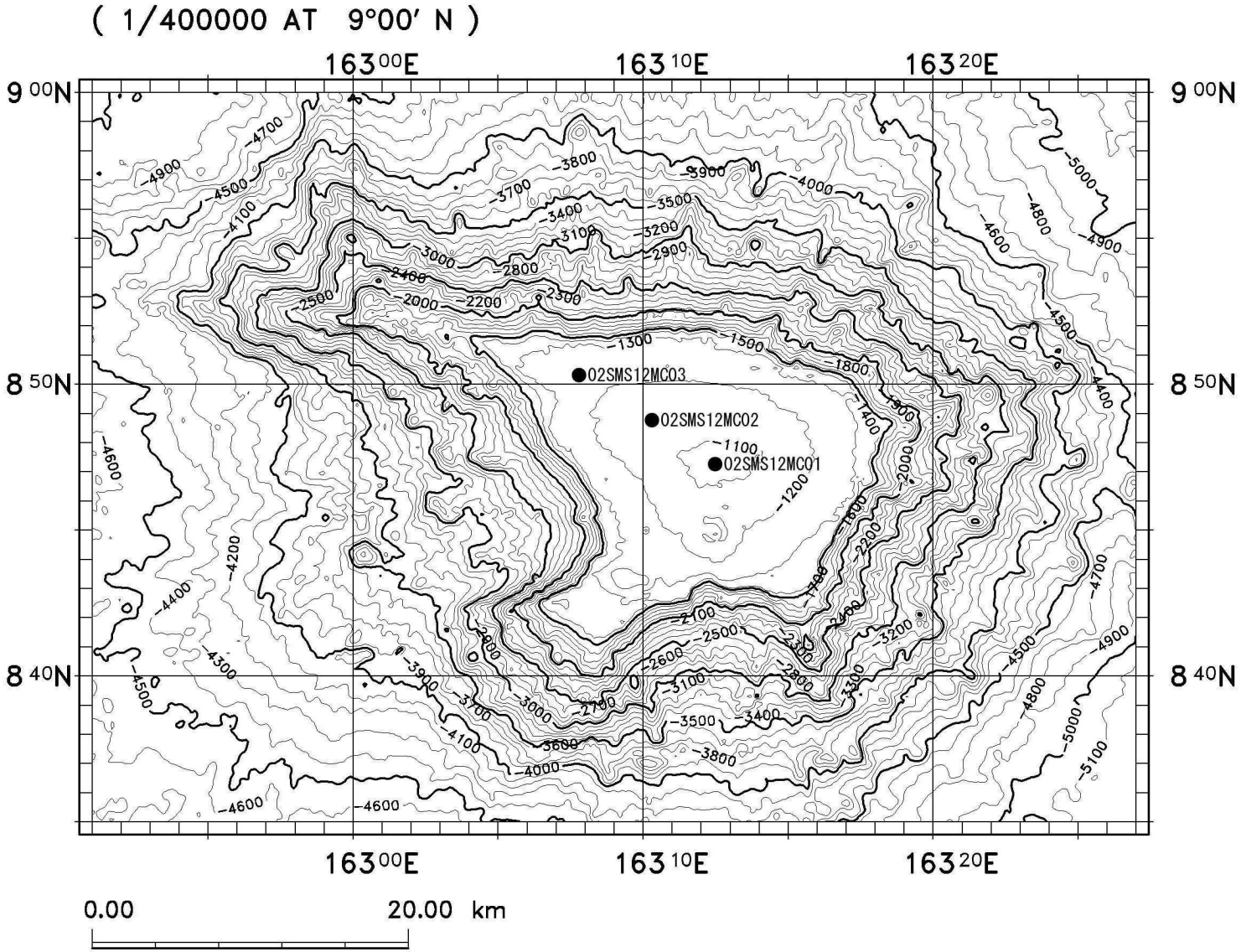


Figure 3-5-1-3 Location Map of Sampling Sites (MS12 Seamount)

3 - 5 - 2　Benthic Organisms

3 - 5 - 2 - 1　Meiobenthos

（1）Fauna

Twelve phyla, including protozoa, were identified from the meiobenthos samples (Table 3-5-2-1). Foraminifera, Nematoda, Mollusca, Sipuncula, Polychaeta and Arthropoda were also found in the macrobenthos fauna samples. Within those phyla, Cnidaria was found only at the MS01 seamount and Sipuncula at MS12. From examination of the faunal compositions of the metazoan meiobenthos, it was found that nematodes were the most abundant followed by arthropods. Faunal compositions of the MS01 and MS12 samples were similar, but the proportion of arthropods in the MS11 samples was greater than at the other seamounts (Figure 3-5-2-1).

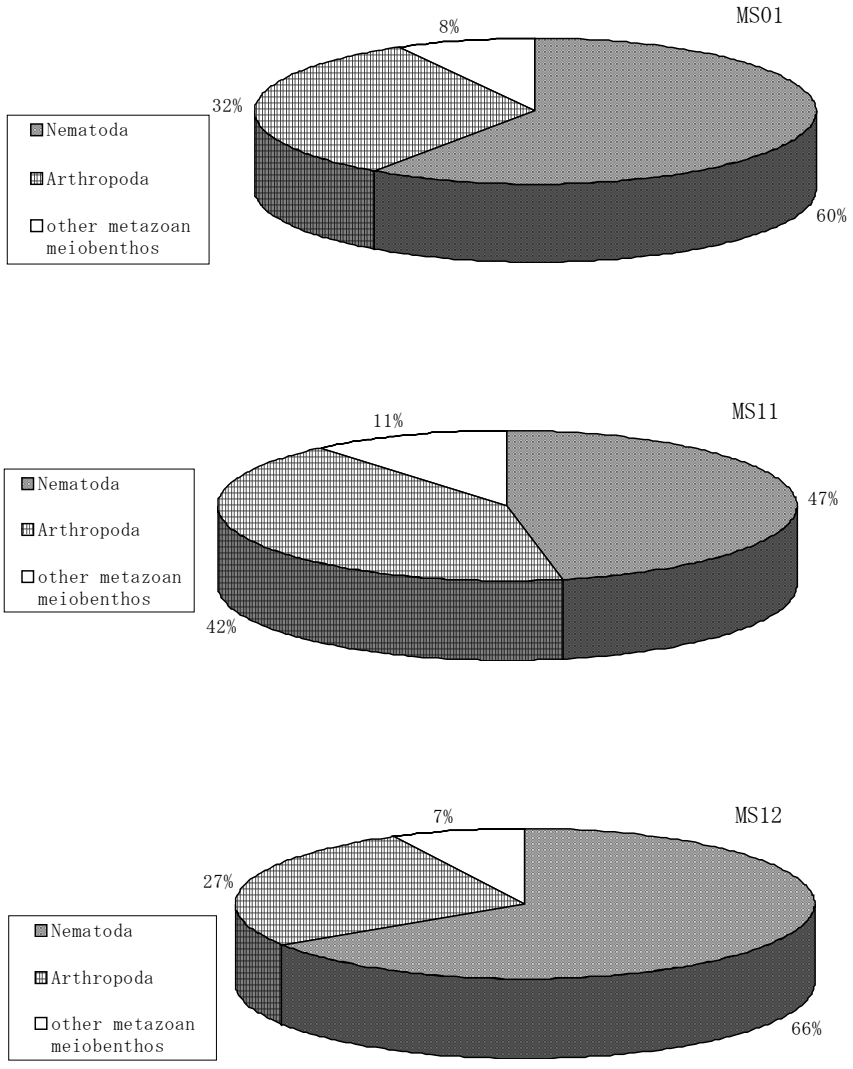


Figure 3-5-2-1 Faunal Composition of Metazoan Meiobenthos

Table 3-5-2-1 Sampled Meiofauna

No.	Taxa	MS01	MS11	MS12
1	Foraminiferida	●	●	●
2	CILIOPHORA	●	●	●
3	CNIDARIA	●		
4	GASTROTRICHA	●	●	●
5	Desmoscolecidae	●	●	●
6	Epsilonematidae	●	●	●
7	Draconematidae			●
8	NEMATODA	●	●	●
9	KINORHYNCHA	●		●
10	LORICIFERA	●	●	
11	TARDIGRADA	●	●	●
12	CAUDOFOVEATA	●	●	
13	GASTROPODA	●		●
14	SIPUNCULA			●
15	Sabellida			●
16	POLYCHAETA	●	●	●
17	Acarina			●
18	Ostracoda	●	●	●
19	Harpacticoida	●	●	●
20	Nauplius	●	●	●
21	Tanaidacea	●		●
22	CRUSTACEA	●		

（２）Abundance (except Protozoa)

Abundance of the total metazoan meiobenthos in the MS01 area, there were no clear differences in abundances between the stations i.e., 70±4 inds./10 cm² (mean±SD) at MC01, 79±0.4 inds./10 cm² at MC02, 73±55 inds./10 cm² at MC03, and 76±26 inds./10 cm² at MC04. At the MS11 seamount, abundances were rather small at MC01, which had only 47±1 inds./10 cm². However, similar abundance levels were observed at the other stations, i.e., 85±41 inds./10cm² at MC02, 73±11 inds./10 cm² at MC03 and 82±24 inds./10 cm² at MC04. At the MS12 seamount abundances were 134±31 inds./10 cm² at MC01, 98±28 inds./10 cm² at MC02, and 56±4 inds./10 cm² at MC03. This demonstrated that the number of metazoan meiobenthos at station MC01 was two times greater than at MC03 (Figure 3-5-2-2a).

The abundance of nematodes at the MS01 seamount, lower abundances were observed at MC01 (43±3 inds./10 cm²) and MC02 (31±12 inds./10 cm²), while greater abundances were at recorded MC03 (52 ± 37 inds./10 cm²) and MC04 (52 ± 7 inds./10 cm²). In the MS11 samples, the least abundance was observed at MC01 (16±3 inds./10 cm²). The abundance of nematodes increase across stations in the following order: MC02 (32±16 inds./10 cm²), MC03 (35±8 inds./10 cm²), and MC04 (52±14 inds./10 cm²). In the MS12, similar to the trends in the abundance of the total metazoan meiobenthos, the abundance of nematodes decreased across stations in the following order: MC01 (92±38 inds./10 cm²), MC02 (67±11 inds./10 cm²) and MC03 (28±2 inds./10 cm²) (Figure 3-5-2-2b). Similar abundances of arthropods were recorded from the MS11 and MS12 samples, but there was greater variation in the MS01 samples (Figure 3-5-2-2c).

（３）Vertical Distribution (except Protozoa)

Total metazoan meiobenthos were concentrated at the surface of the sediment and their density decreased with the depth from the surface at every station of every seamount (Figure 3-5-2-3a). However, the pattern of reduction was different among stations. In particular, an especially high concentration was recorded at the surface of station MC04 at MS11 and at MC01 of MS12.

Maximum abundances of nematodes and arthropods were observed not only in the surface layer, but also in the 1-2 cm and 2-3 cm layers. However, reduction curves produced from the vertical profile sampling show a decrease in abundance from the upper to the lower layers – as they did for the total metazoan meiobenthos (Figures 3-5-2-3b, c). Within these phyla, high concentrations of nematodes were observed at the surface of the sediment at station MC01 and MC04 of seamount MS01, at MC04 of MS11

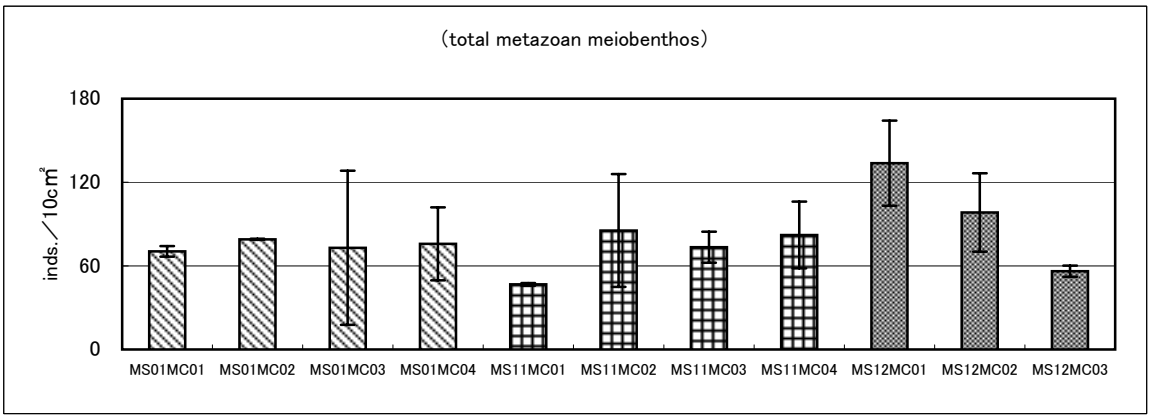


Figure 3-5-2-2a Abundance of Metazoan Meiobenthos

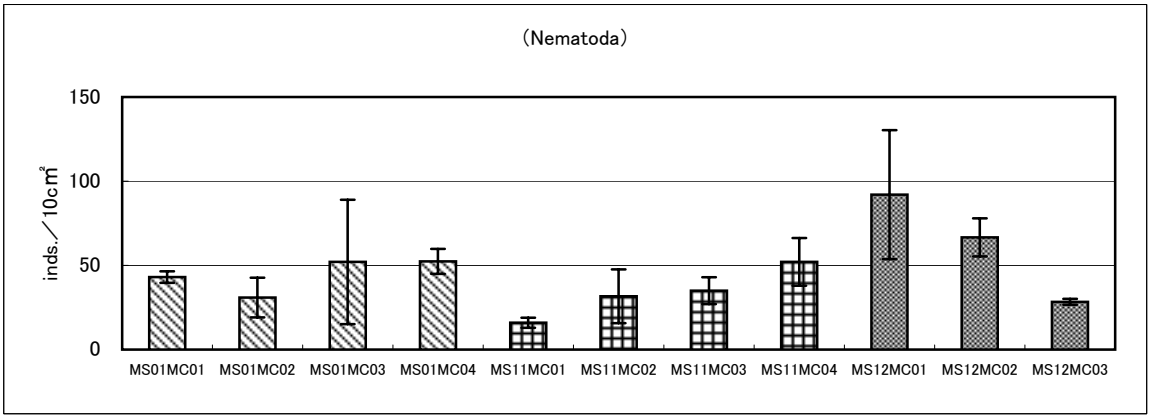


Figure 3-5-2-2b Abundance of Nematoda

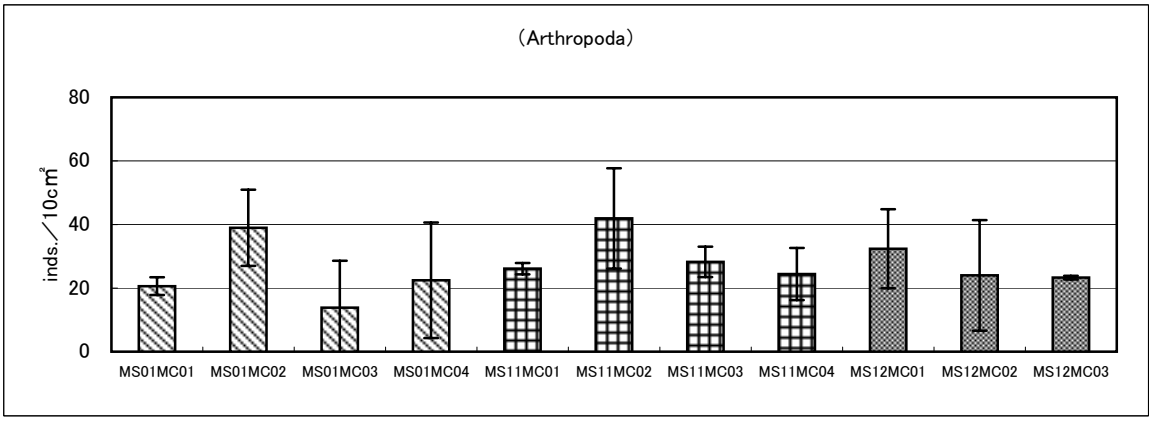


Figure 3-5-2-2c Abundance of Arthropoda

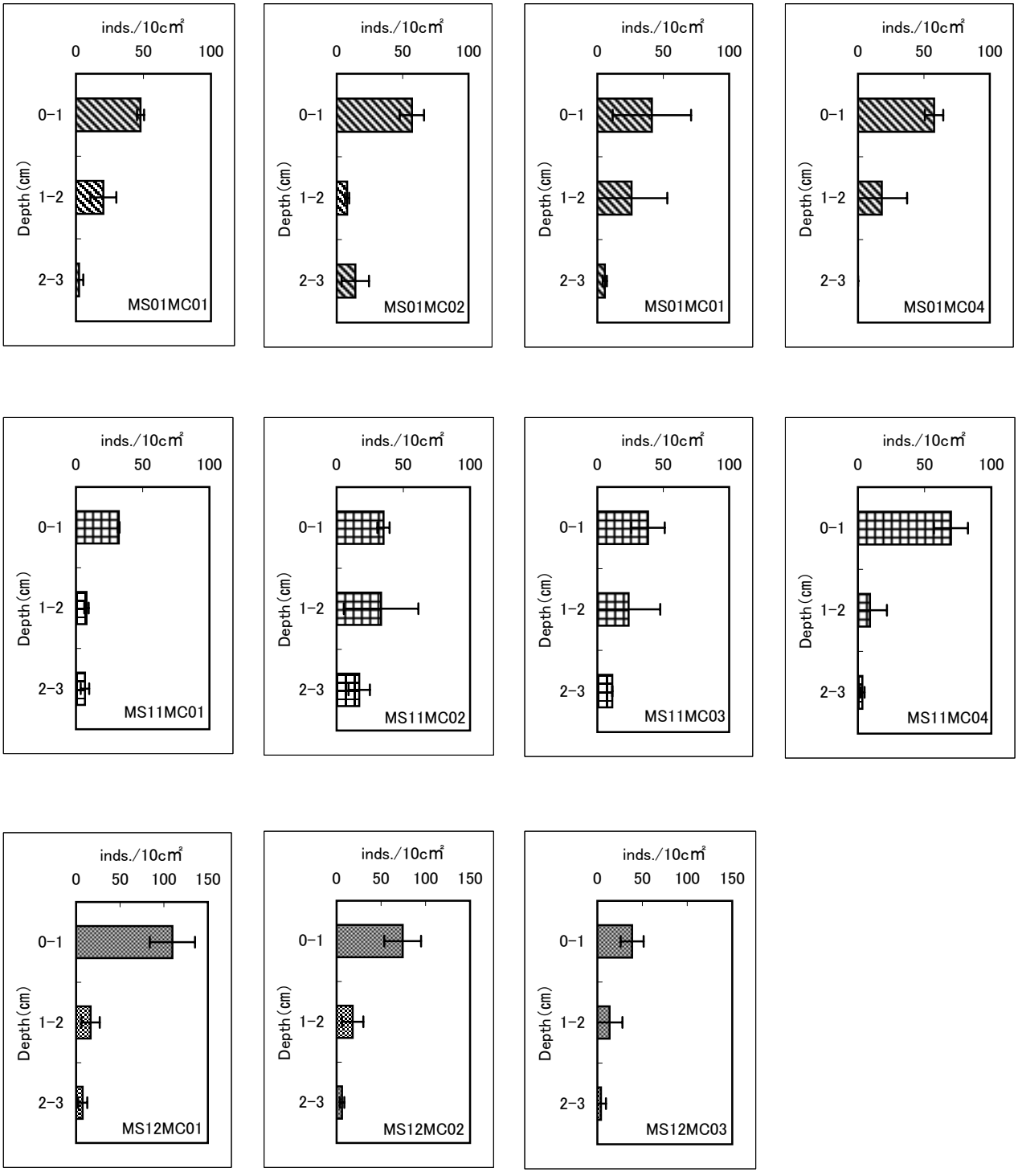


Figure 3-5-2-3a Vertical Distribution of Metazoan Meiobenthos at Each Station

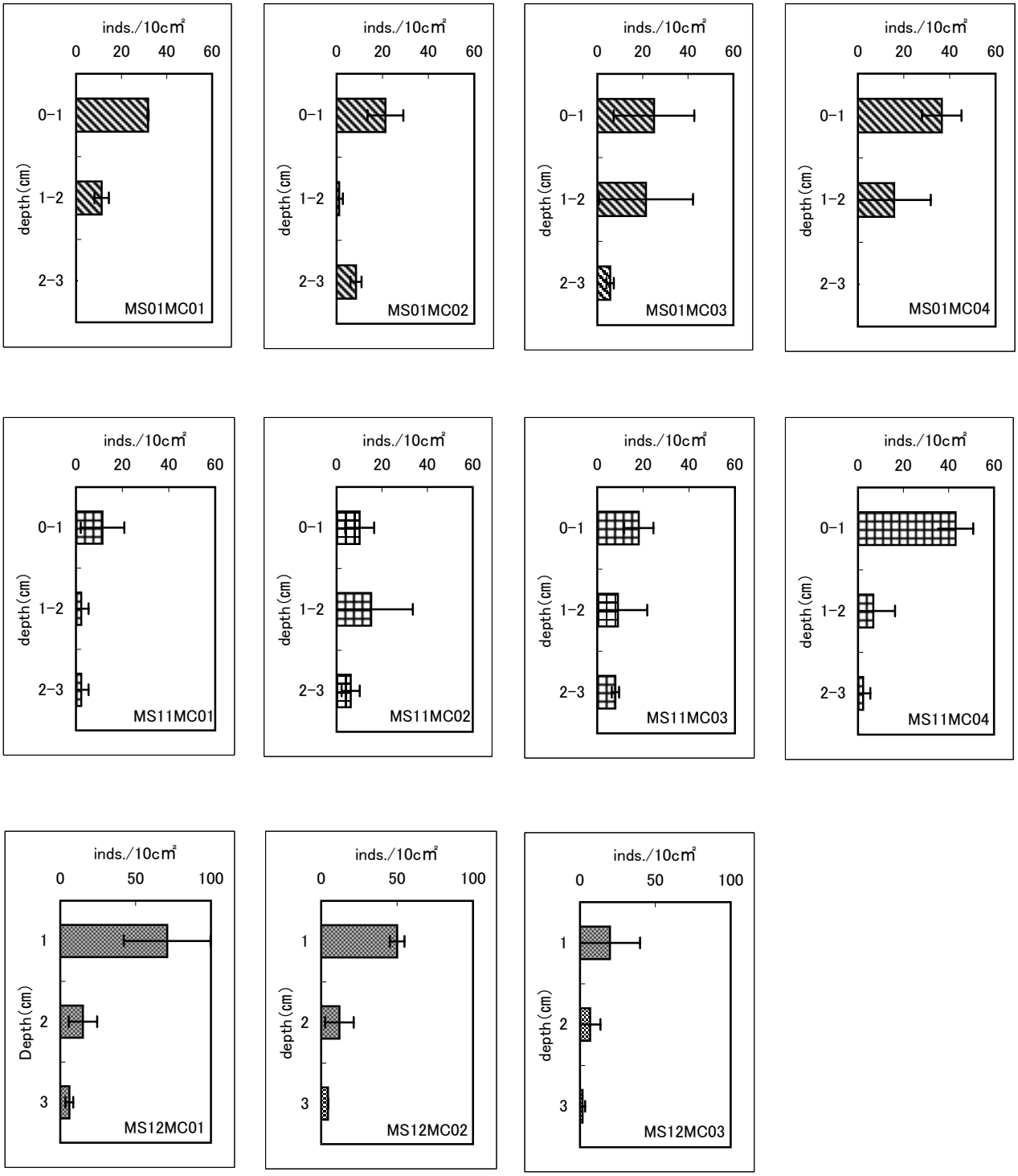


Figure 3-5-2-3b Vertical Distribution of Nematoda at Each Station

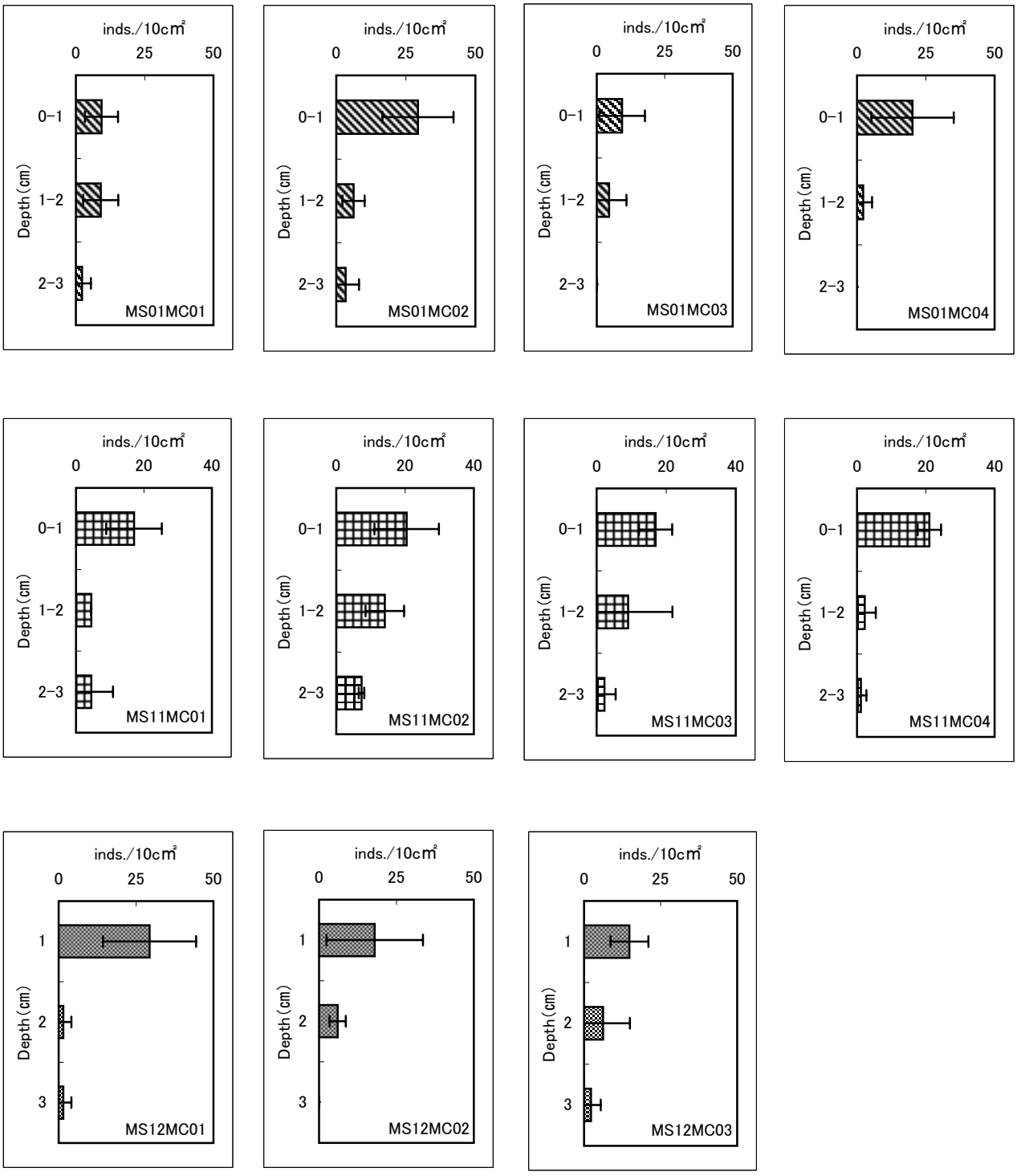


Figure 3-5-2-3c Vertical Distribution of Arthropoda at Each Station

and at MC01 of MS12. Arthropods were in high concentrations at MC02 of MS01 and at MC01 of MS12.

3 - 5 - 2 - 2　Macrobenthos

（1）Fauna

Ten phyla, including protozoa, were identified as macrobenthos (Table 3-5-2-2). Foraminifera, Nematoda, Annelida and Arthropoda were also found in the meiobenthos fauna. Within these phyla, Porifera and Ectoprocta appeared only in the MS01 samples, and Urochordata in the MS12 samples. Annelida were the most abundant phyla in the faunal compositions of the metazoan macrobenthos, followed by the Nematoda and Arthropoda that had similar abundances (Figure 3-5-2-4).

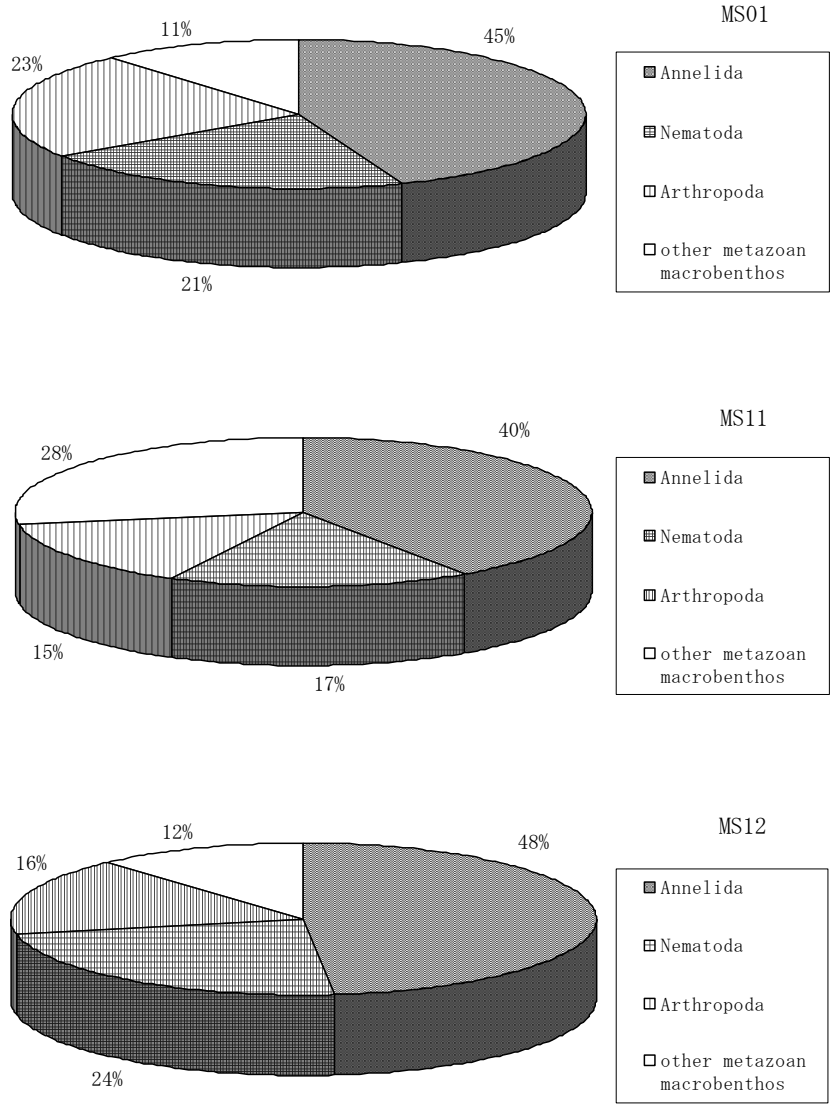


Figure 3-5-2-4　Faunal Composition of Metazoan Macrobenthos

Table 3-5-2-2 Sampled Macrofauna

No.	Taxa	MS01	MS11	MS12
1	Foraminiferida	●	●	●
2	PORIFERA	●		
3	NEMATODA	●	●	●
4	CAUDOFOVATA	●	●	●
5	Limidae	●	●	
6	BIVALVIA	●	●	
7	Godilida			●
8	GASTROPODA		●	●
9	SIPUNCULA	●	●	●
10	Phyllodocidae		●	
11	Hesionidae			●
12	Pilargiidae			●
13	Syllidae	●		
14	Glyceridae	●	●	●
15	Goniadidae	●		●
16	Onuphidae	●	●	
17	Lumbrineridae	●		●
18	Dorvilleidae		●	●
19	Eunicida			●
20	Paraonidae	●	●	●
21	Spionidae	●	●	
22	Cirratulidae	●	●	●
23	Flabelligeridae	●	●	●
24	Opheliidae		●	
25	Oweniidae			●
26	Ampharetidae	●		
27	Terebellidae	●	●	●
28	Sabellidae	●		●
29	POLYCHAETA	●	●	●
30	Nolellidae	●		
31	Acarina			●
32	Ostracoda	●		●
33	Harpacticoida	●	●	●
34	Tanaidacea	●		●
35	Isopoda		●	
36	Gammaridea	●		
37	OPHIUROIDEA		●	●
38	ASCIDIACEA			●

（２）Abundance (except Protozoa and Porifera)

Abundance of the total metazoan macrobenthos in the MS01 samples were 565±502 inds./m^2 (mean±SD) at MC01, 635±499 inds./m^2 at MC02, 706±599 inds./m^2 at MC03, and 1223±454 inds./m^2 at MC04. The number of metazoan macrobenthos at MC04 was two times greater than that of MC01. In the MS11 samples, the abundance of metazoan macrobenthos was 235±216 inds./m^2 at MC01, 212±299 inds./m^2 at MC02 , 459±371 inds./m^2 at MC03 and 1223 ± 216 inds./m^2 at MC04. Abundance of metazoan macrobenthos at MC01 was similar to MC02, but the abundance recorded from the MC04 samples was five times greater than those of MC01 and MC02. At the stations of MS12, the abundance of total metazoan macrobenthos were 1976±615 inds./m^2 at station MC01, 1694±1198 inds./m^2 at MC02, and 670±533 inds./m^2 at MC03, which demonstrated that the number of metazoan macrobenthos at station MC01 was three times greater than that of MC03 (Figure 3-5-2-5a).

The greatest variation was observed in the abundance of annelids at the MS01 seamount. In the MS11 samples, a low abundance of annelids was observed at MC01 (141±141 inds./m^2) and there were no annelids at MC02 (0 inds./m^2). And it increased across stations in the following order: MC03 (176 ± 267inds./m^2), MC04 (518 ± 454 inds./m^2). In the MS12 samples, similar to the results for the total metazoan macrobenthos, the abundance of annelids decreased across stations in the following order: MC01 (1082±496 inds./m^2), MC02 (706±998 inds./m^2) and MC03 (282±305 inds./m^2) (Figure 3-5-2-5b).

At the MS01 seamount, there was a lower abundance of nematodes at MC01 and MC02, and increased across stations MC03 and MC04. Similar to the abundances recorded for annelids, there were no nematodes at stations MC01 and MC02, and their abundance increased at stations MC03、MC04 of the MS11 seamount. A different pattern to that of the total metazoan macrobenthos was observed in the nematodes, such that the greatest abundance was observed at station MC02 (635±299 inds./m^2) of the MS12 seamount (Figure 3-5-2-5c).

The greatest variation was observed in the abundance of arthropods at MS01 and MS11. In the MS12 samples, similar to the pattern of abundance recorded for total metazoan macrobenthos, the abundance of arthropods decreased across stations in the following order: MC01 (423±141 inds./m^2), MC02 (141±200 inds./m^2) and MC03 (106±135 inds./m^2) (Figure 3-5-2-5d).

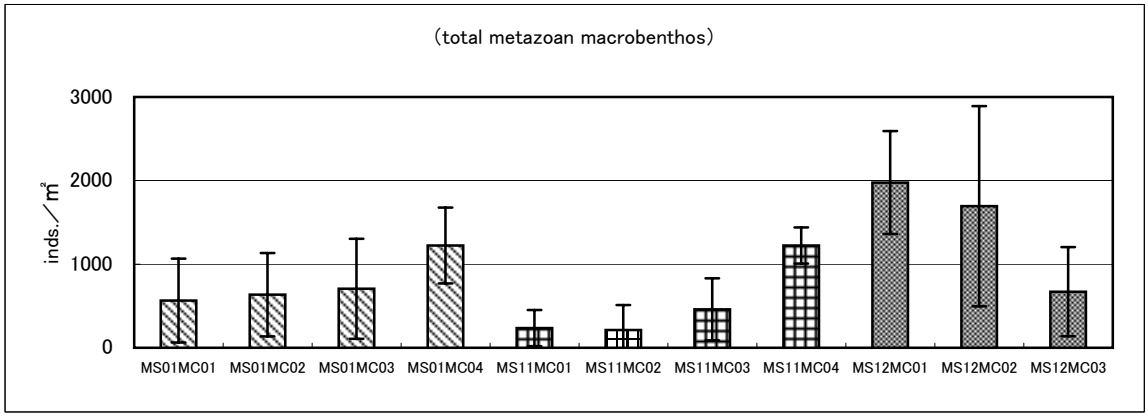


Figure 3-5-2-5a Abundance of Metazoan Macrobenthos

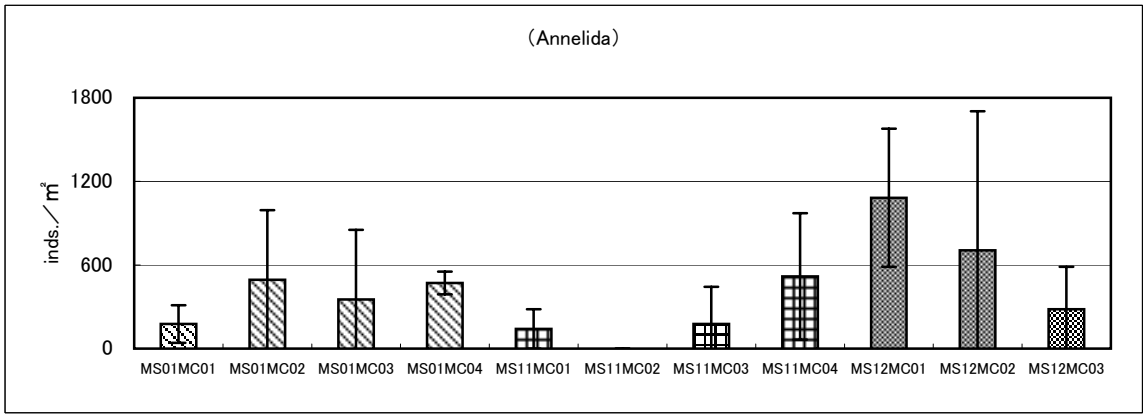


Figure 3-5-2-5b Abundance of Annelida

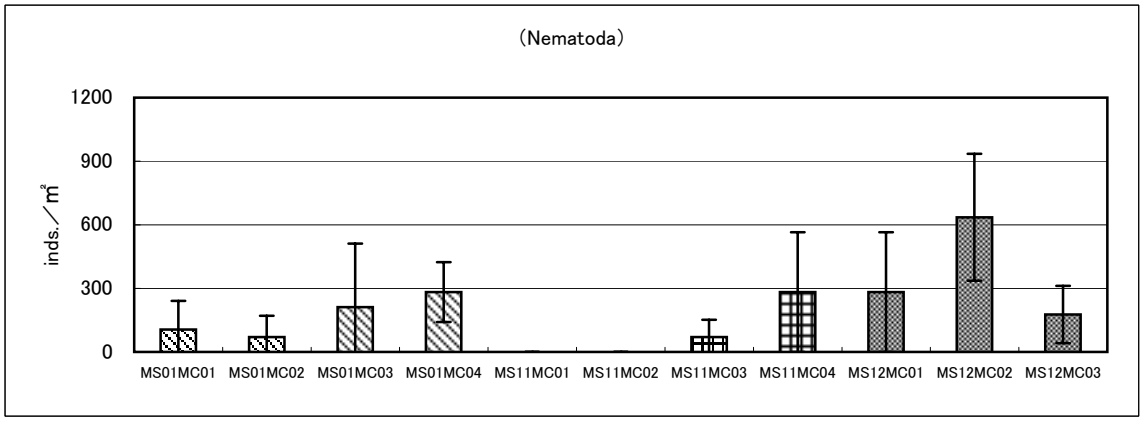


Figure 3-5-2-5c Abundance of Nematoda

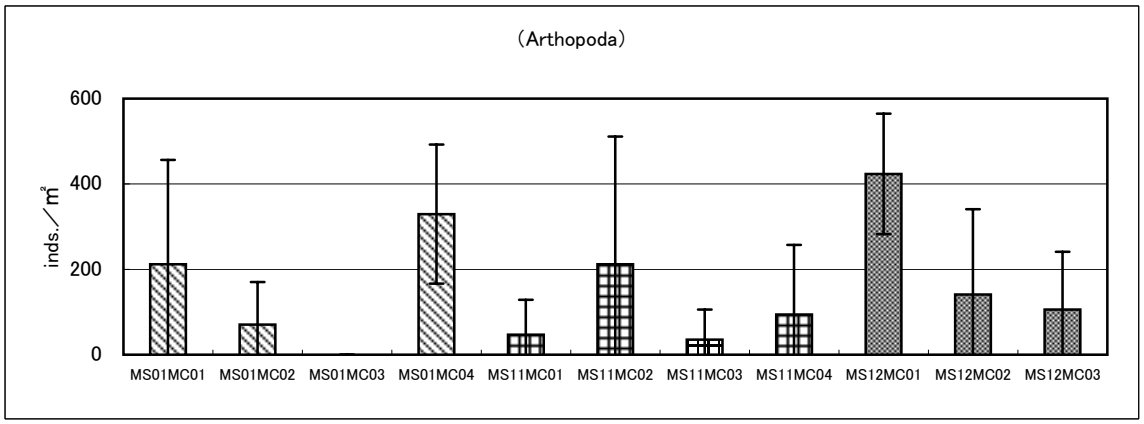
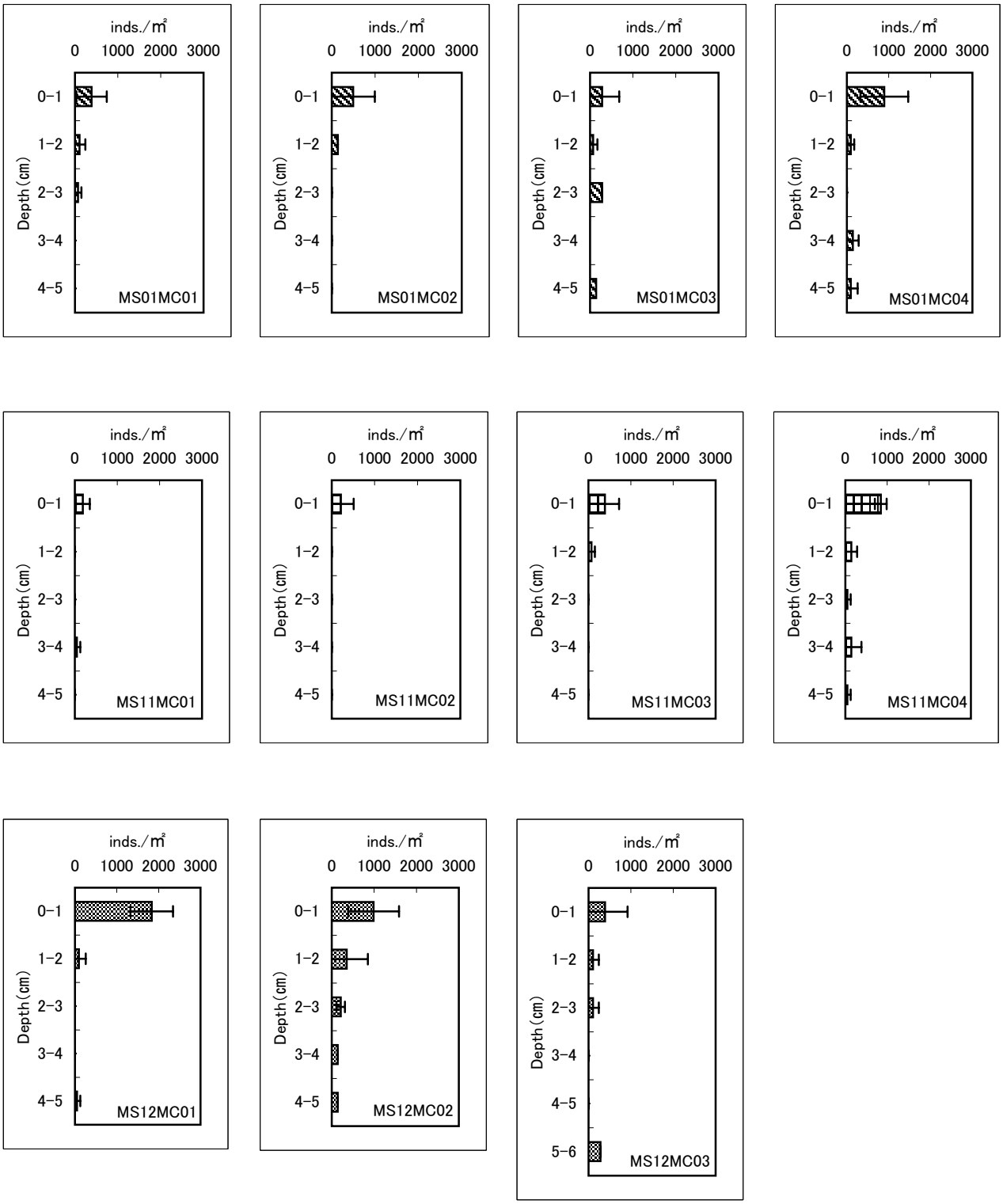


Figure 3-5-2-5d Abundance of Arthropoda

（３）Vertical Distribution (except Protozoa and Porifera)

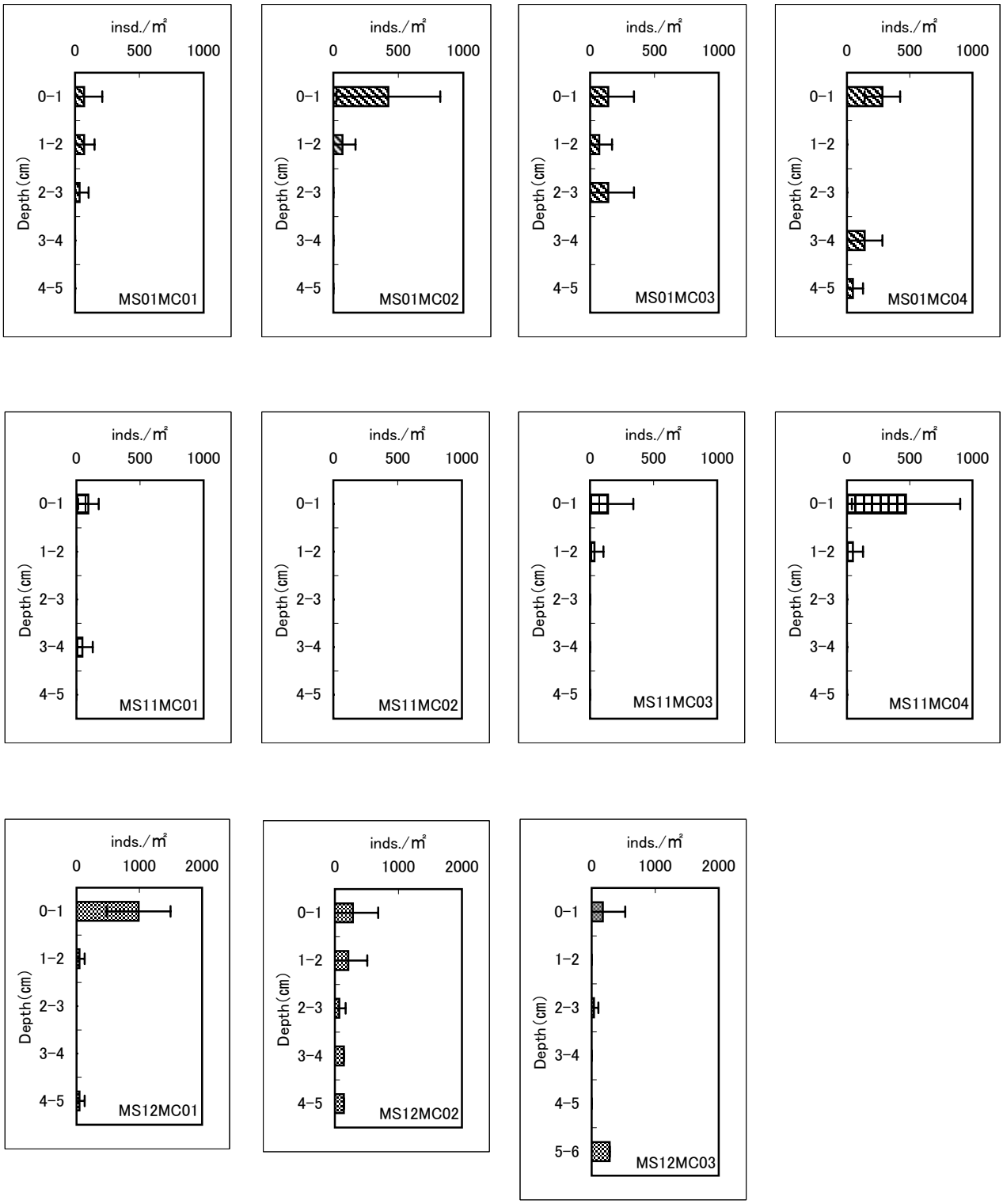
Total metazoan macrobenthos were concentrated in the surface layer of the sediment and their density decreased with depth (from the surface) at every station of every seamount (Figure 3-5-2-6a). However, the pattern of reduction was different among stations. In particular, high concentrations were recorded at the surface of station MC04 of seamount MS01, at MC04 of MS11 and at MC01 of MS12.

A general pattern in the vertical profiles for annelids, nematodes and arthropods indicated reductions in abundance as the pattern of the total metazoan macrobenthos. However, maximum abundances were not only observed at the surface layer (Figures 3-5-2-6b, c and d) From comparisons between each faunal group, arthropods were in the greatest concentrations at the surface followed by annelids and nematodes. High concentrations of annelids were observed at the sediment surface at station MC02 of seamount MS01, MC04 of MS11 and MC01 of MS12. High concentrations of nematodes were observed at the surface of the sediment at MC01 of MS12. Arthropods were only observed at the surface of the sediment at every station.



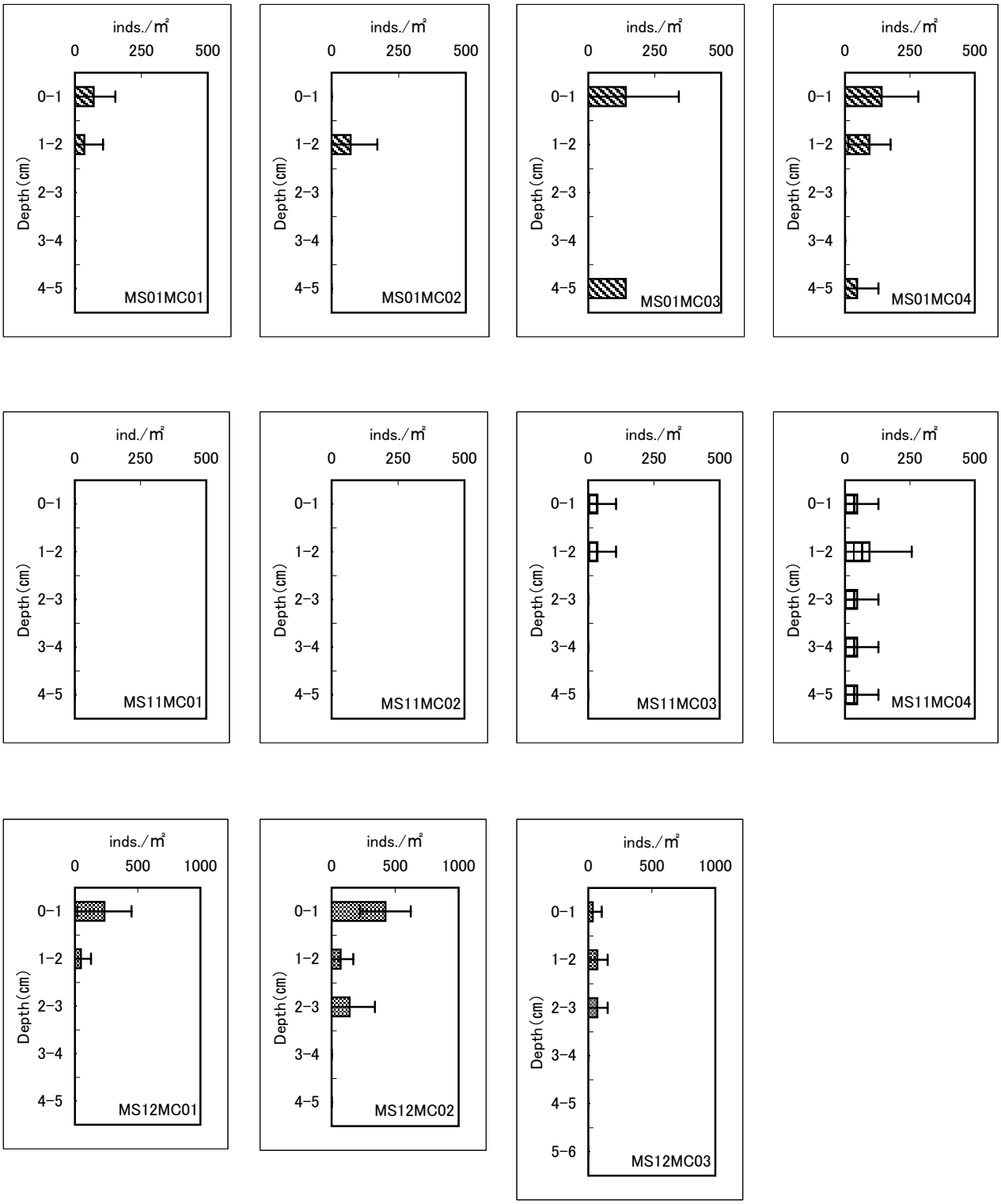
* Abundance was calculated from a single sample for the 3-4 cm and 4-5 cm of the MS01 MC03 core, the 3-4 cm and 4-5 cm of the MC02 core and the 5-6 cm of the MC03 core of the MS12 seamount.

Figure 3-5-2-6a Vertical Distribution of Metazoan Macrobenthos at Each Station



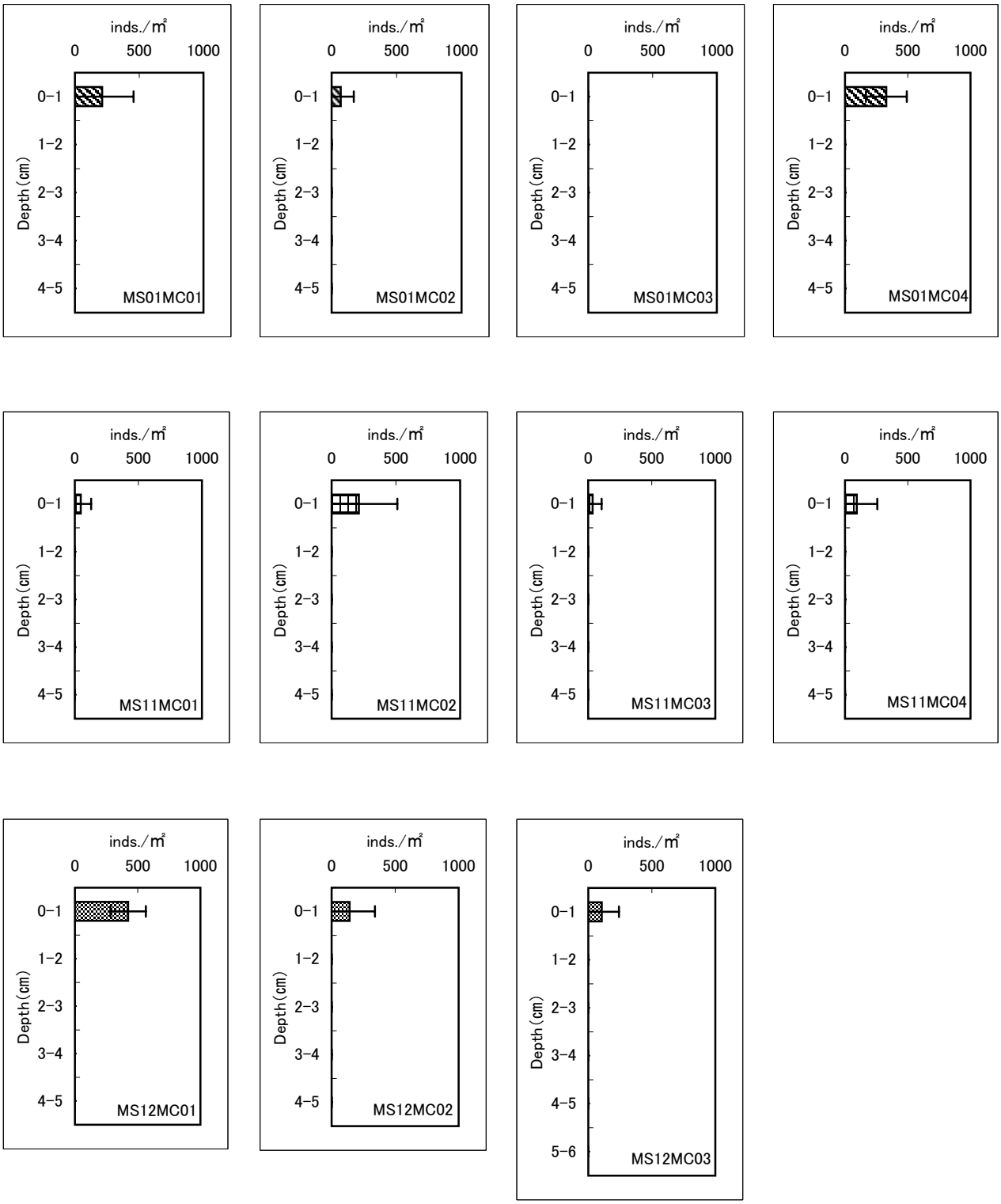
* Abundance was calculated from a single sample for the 3-4 cm and 4-5 cm of the MS01 MC03 core, the 3-4 cm and 4-5 cm of the MC02 core and the 5-6 cm of the MC03 core of the MS12 seamount.

Figure 3-5-2-6b Vertical Distribution of Annelida at Each Station



* Abundance was calculated from a single sample for the 3-4 cm and 4-5 cm of the MS01 MC03 core, the 3-4 cm and 4-5 cm of the MC02 core and the 5-6 cm of the MC03 core of the MS12 seamount.

Figure 3-5-2-6c Vertical Distribution of Nematoda at Each Station



* Abundance was calculated from a single sample for the 3-4 cm and 4-5 cm of the MS01 MC03 core, the 3-4 cm and 4-5 cm of the MC02 core and the 5-6 cm of the MC03 core of the MS12 seamount.

Figure 3-5-2-6d Vertical Distribution of Arthropoda at Each Station

3 - 5 - 3　Sediment Properties

3 - 5 - 3 - 1　Total Organic Carbon

Investigation of the vertical distributions of total organic carbon (TOC) found that it was greatest in the 0-1 cm layer at all stations. There was a tendency for TOC to decrease with depth from the surface, however a few stations had an increase in the 2-3 cm layer (Figure 3-5-3-1). The range of observed TOC values across all stations in each layer were: 0.63~1.66 mg/g(D) in the 0-1cm layer, 0.54~1.09 mg/g(D) in the 1-2cm layer, and 0.52~0.99 mg/g(D) in the 2-3 cm layer.

At the MS01 seamount, although there was little variation between the 1-2 cm and 2-3 cm layers in total organic carbon concentrations at stations MC01 and MC03, the concentration decreased with depth from the surface layers. A little variation was observed vertically, and similar concentrations were recorded from every layer at MC02. The mean concentration of 1.02±0.05 mg/g(D) was observed in the 0-1 cm layer at MC04, but it decreased in the 1-2 cm layer, then increased again in the 2-3 cm layer.
At the MS11 seamount, the concentrations were low in every layer at stations MC01 and MC02, and only a little variation was observed vertically. However, the concentrations decreased with depth from the surface layers at stations MC03 and MC04. The concentrations in every layer at MC03 and MC04 were higher than those of MC01 and MC02. The greatest concentration of 1.10±0.02 mg/g(D) was observed in the 0-1 cm layer of MC04.

At the MS12 seamount, there were high concentrations of over 1 mg/g(D) in the 0-1 cm layers of stations MC01 and MC02. However, the concentrations were 0.94±0.01 mg/g(D) in the 0-1 cm layer and 0.94±0.03 mg/g(D) in the 2-3 cm layer at MC03, where little variation was observed through the vertical profile.

3 - 5 - 3 - 2　Total Nitrogen

Investigation of the vertical distribution of total nitrogen (TN) found that it was greatest in the 0-1 cm layer of almost all stations. However there were some variations such as the greatest concentration being observed in the 1-2 cm layer of station MC03 at seamount MS12 (Figure 3-5-3-2). The concentrations were 0.11~0.24 mg/g(D) at 0-1 cm layers, 0.09~0.20 mg/g(D) in the 1-2 cm layers and 0.08~0.22 mg/g(D) in the 2-3 cm layers at every station.

At the MS01 seamount, the concentrations were approximately 0.20mg/g(D) in the 0-1 cm layers at every station, these were slightly higher concentrations than at the other seamounts. The concentrations decreased with depth from the surface layers at MC01 and MC03, but MC02 and MC04 lacked this tendency.

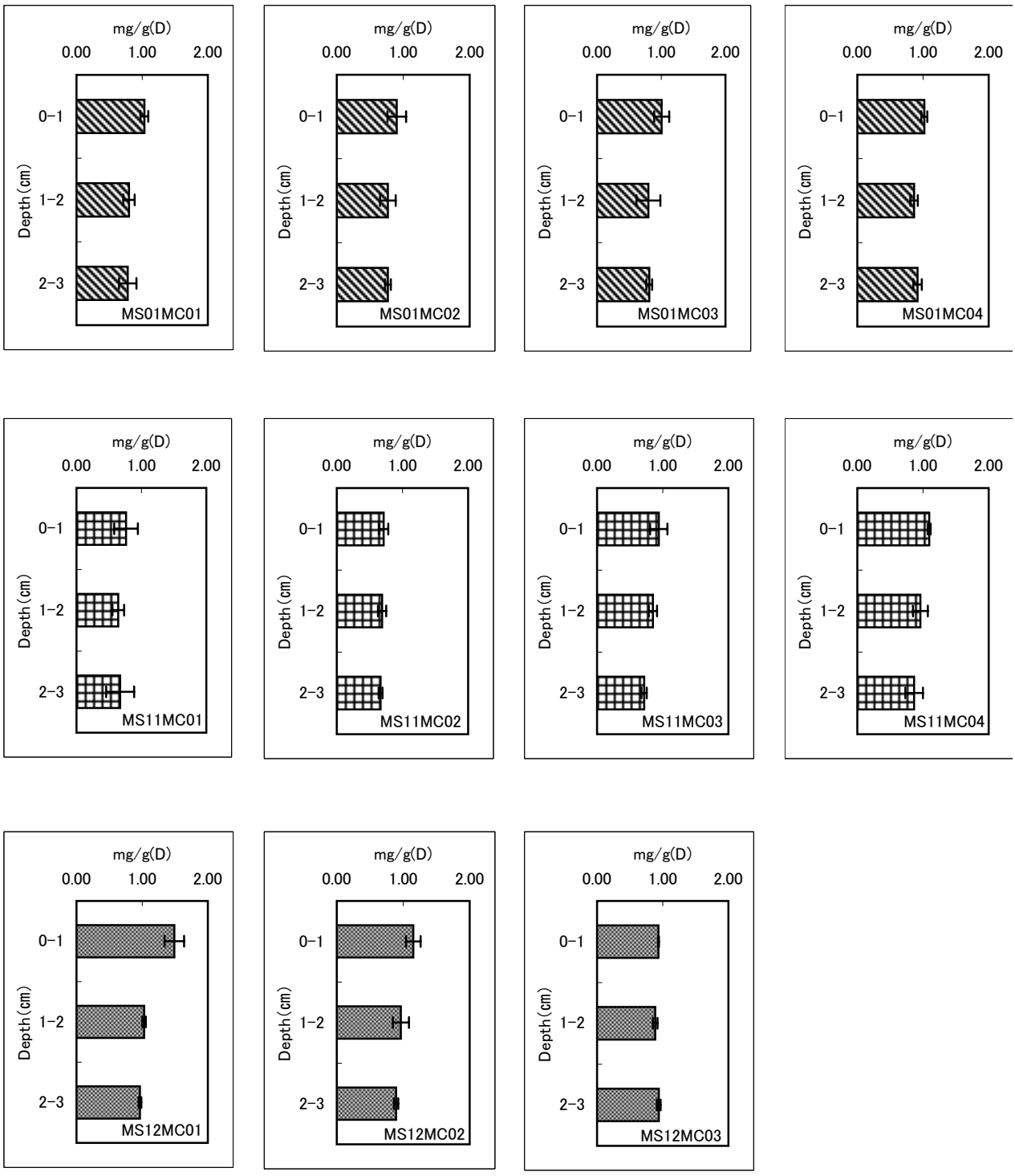


Figure 3-5-3-1 Vertical Distribution of Total Organic Carbon

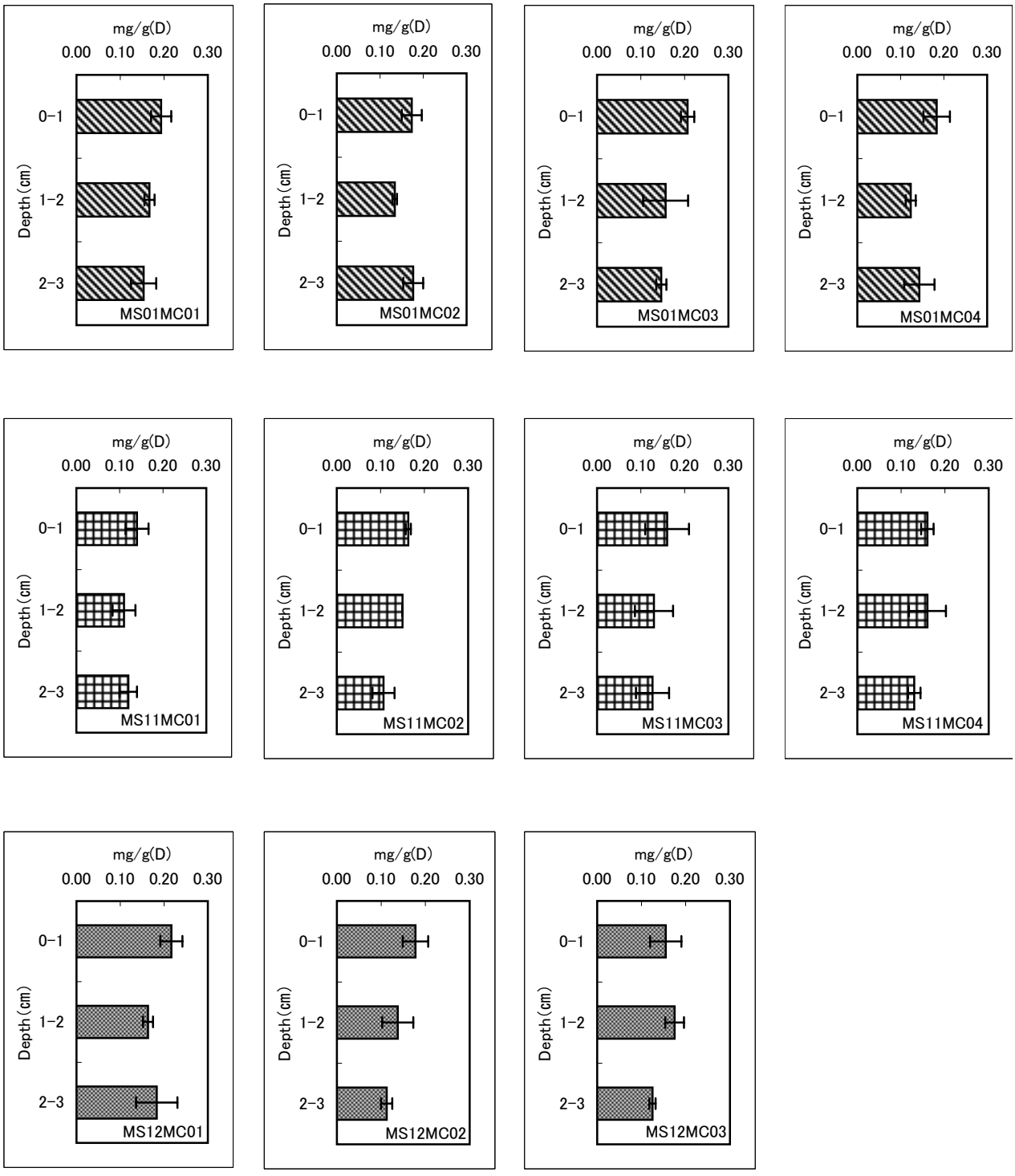


Figure 3-5-3-2 Vertical Distribution of Total Nitrogen

At the MS11 seamount, the concentrations of TN decreased with depth from the surface layers at stations MC02 and MC03, and the concentrations of TN in the 0-1cm layer were almost the same at 0.16 mg/g(D) (SD;±0.01 at MC02,±0.05 at MC03). The concentrations at MC01 were similar in comparison to MC02 and MC03, however there was a lower concentration in the 1-2 cm layer than in the 2-3 cm layer (at MC01). The concentrations in the 0-1 cm and the 1-2 cm layer of MC04 were 0.16 mg/g(D) (SD; ±0.01 at 0-1 cm, ±0.04 at 1-2 cm), there was no significant difference between sediment surface and 2 cm layer.

At the MS12 seamount, the concentrations of TN decreased with depth from the surface layer at station MC02 only. The low concentration of 0.16±0.01 mg/g(D) was observed in the 1-2 cm layer of MC01, and the high concentration of 0.18±0.02 mg/g(D) was in the 1-2 cm layer of MC03.

3 - 5 - 4 Conclusion

At the MS01 seamount, samples were collected from the top (MC03 and MC04), and at sites 200 m deeper than there (MC01 and MC02). Although remarkable differences were not observed in the total metazoan meiobenthos, nematode abundances in MC03 and MC04 samples were greater than those of MC01 and MC02. The total abundance of metazoan macrobenthos increased across stations following the order of MC01, MC02, MC03 and MC04. Also high concentrations were observed in surface layers vertically. The concentrations of total nitrogen at the surface of each of these stations were higher than those of the other survey areas.

There were four sampling stations at the MS11 seamount: i.e., MC03 and MC04 at the top, MC02 at about 200 m deeper than there, and then MC01 at 400 m deeper. However, the total abundance of metazoan meiobenthos did not show large variation. The abundance of nematodes, which was the dominant fauna, increased across the stations in the following order: MC01, MC02, MC03 and MC04. High concentrations of nematodes observed in vertical profiles were also remarkable across this order of stations. The total abundance of metazoan macrobenthos increased in this same station order; and high concentrations were observed in surface layers vertically. The concentrations of total organic carbon decreased with increasing sediment depth at station MC03 and MC04 of this seamount.

At the MS12 seamount, samples were collected from the top (MC01), and at sites 100 m (MC02), and 200 m (MC03) deeper than there. The abundance of metazoan meiobenthos decreased with increasing water depth, and their concentrations were also high in the surface layer significantly. Similar to the meiobenthos, the abundance of metazoan macrobenthos decreased with increasing water depth, and their high concentrations were remarkable in the surface layer. Sediment properties did not show clear trends as they did in the benthos, but concentrations of total nitrogen decreased with sediment depth at MC02 of this seamount.

It was found in this study that differences of the abundance of meiobenthos and macrobenthos in three seamounts areas, there was the greatest abundance of those organisms in the MS12 compared with the stations at the top of seamounts.

The distance of the sampling stations in each area was so close that it is natural to consider that the supply of organic matter from the surface would be the same within the area. Organic matter, the quantity of which reflects the feeding conditions of benthic organisms, is likely to accumulate at the top of a seamount, and not on its slopes. Further, it has been said generally that the abundance of benthic organisms is mainly

controlled by the quantity of organic matter available. Judging from the results and the assumptions, it is possible to assume that differences in topography influence the accumulation of organic matter, which means there is heterogeneity in the feeding conditions for benthic organisms on seamounts. This was reflected in the abundances of benthic organisms in each area.

Chapter 4 Conclusions

The survey of cobalt crust in the Exclusive Economic Zone (EEZ) of the Republic of the Marshall Islands has been carried out in fiscal years of 1996 and 1998 for the thirteen seamounts in the area and as the results, bathymetric information and acoustic intensity reflection image were obtained and samples were collected mainly by dredging.

On the basis of such information, the survey of this year was carried out for the purpose of understanding the occurrence of the cobalt crust at the selected seamounts where the seafloor was flat and the distribution of cobalt crust was expected. The deepsea boring system (BMS) was used and columnar sampling was conducted at the areas. Moreover, the environmental survey was carried out to understand the environmental characteristics of the sea area.

On the selection of the seamount for the survey, wide extension of flat seafloor, characteristic nature representing the seamount of the Republic of the Marshall Islands, were taken into consideration and three seamounts, MS01, MS11, and MS12 were selected.

4-1 Occurrence of Cobalt Crust

In the survey of this year, four to seven survey sites were selected from the areas of gentle slope and expected exposure of cobalt crust, taking into account of easier exploitation in the future, and four to six holes (points) were drilled at each site. In case drilling was obliged to cancel due to bad weather, sampling by the large gravity corer (LC) was conducted.

The purpose of the survey is to understand nature of cobalt crust distribution in the summit area and in different water depths and to clarify horizontal continuity and occurrences under sediment coverage.

4-1-1 Results of the Survey

The results of the survey are summarized in Table 4-1-1. The survey results of each seamount are as follows.

4-1-1-1 MS01 Seamount

The MS01 seamount is a table seamount situated in the north edge of the Ralik Seamount Chain, with the shallowest water depth of 1,040m, relative height of 4,000m, and the horizontal extension of about 70km to E-W, and about 60km to N-S direction.

Table 4-1-1-1 Results of the Survey

		MS01Seamount	MS11Seamount	MS12 Seamount
Type of Seamount		Flat Summit (dome shape)	Flat Summit (dome shape)	Flat Summit (dome shape)
Lower Boundary of Summit (m)		1,600	2,100	1,400
Area of Summit (km^2)		443	670	295
Exposed Area of Summit (km^2)		126	242	134
Exposure		Exposed area is distributed at the margin of summit	Exposed area is distributed in the area from margin of summit to	Exposed area is distributed at margin of summit.
Geology		calcareous and phosphoric conglomerate with basalt pebbles	basalt, limestone	basalt, limestone, calcareous conglomerate
Fossil Age of Calcareous Rock		Cretaceous, Middle Eocene	Cretaceous, Lower Eocene	Cretaceous
Ar-Ar Age of Basalt				99.68±1.46Ma (Middle Cretaceous) 110.05±0.51Ma (Middle Cretaceous)
Drilling Site (Hole)		5 (16)	4 (11)	7 (25)
Average Thickness (mm)	2002	59	Summit 132、Slop 160	70
	Previous Year	Maximum 59、Average 36	Maximum 74、Average 36	Maximum 67、Average 24
Co%	2002	0.44	Summit 0.34、Slop 0.37	0.46
	Previous Year	0.63	0.69	0.67
Ni%		0.65	0.39	0.57
Cu%		0.12	0.12	0.05
Mn%		20.71	19.50	22.22
Fe%		11.69	15.01	11.44
Pt ppm		0.87	0.38	0.40

The acoustic reflection intensity distribution is the strongest at the shoulder part of the margin of the summit, and the annular dark acoustic image zone is distributed at water depth of 1,300m to 1,400m, bordering the marginal part of two terraces at the summit and suggesting the zone to be constituted of exposed rock. Other than this area, most of the summit areas are dominated by unconsolidated sediments.

The MS01 seamount is composed of basalt as the basement, but the surface is covered by calcareous or phosphoric conglomerate including basalt pebbles. The development of limestone is poor and the seamount seems to have submerged in comparatively early time. From the result of chemical analysis of basalt and fossil test in calcareous rocks, the basal basalt of the seamount is alkaline basalt formed under oceanic island environment, and after the formation of the seamount by basalt activity, a reef had been formed around the margin of the seamount in Cretaceous Era. In middle Eocene time, the seamount had been submerged to the depth of marine environment to deposit pelagic sediments. The major formation of the cobalt crust had started in Eocene and continued afterward.

The cobalt crust was collected from all the drilling points conducted at the five sites at the area from the margin of the summit to the summit. The average thickness of cobalt crust at each site varies 31mm to 97mm, and the average of all of five sites is 59mm. It is assumed that the average thickness of about 6cm(59mm) of cobalt crust develops in the exposed area of the water depth of 1,200m to 1,600m from the margin of the summit to the summit. The drilling site of this year is located at the summit area with small difference of relative depths and the relation of the thickness of the cobalt crust to water depth is not clear. The results of the previous survey suggested that the thickness of cobalt crust collected at the slope of the seamount was thin compared with that of the summit area and there was a possibility that the thickness of cobalt crust decreased with increase of depths. At the drill point covered by unconsolidated sediments, the thickness of the cobalt crust is thin, compared with the crust sample obtained at the surface of exposed area nearby, and there is a possibility that the thickness of cobalt crust at the point covered by sediments is poorer than that of cobalt crust exposed point. The average grade of Co by the survey of this year at the MS01 seamount is Co 0.44%, Ni 0.65%, Cu 0.12%, Mn 20.71%, Fe 11.69% and Pt 0.87ppm. Compared with the survey result of the 1996, Co and Fe are low and Pt is high. One of the possible reasons for this is that dredge and LC samplings collected incomplete cobalt crust samples dominated by outer layer during the survey of 1996. By layer-by-layer analysis of the crust sample, it is shown that Co and Fe decrease from the outer layer to inner layer and vice versa for Ca and P.

4-1-1-2 MS11Seamount

The MS11 seamount is situated about 100km east of Anewetak Atoll, and sits on the same sea plateau. It is a dome shaped table seamount with relative height of 700m, and the shallowest point is at water depth of 1,495m. The exposure of rock assumed by the acoustic image is distributed from the shoulder to the margin of the summit, and the greater part of the summit area is laid by unconsolidated sediments.

Basalt crops out at the slope of the MS11 seamount, but limestone is distributed occupying the flat area and it is pelagic limestone. From the fossil test, it is assumed that the reef had been formed at the margin of the seamount in Cretaceous Era and limestone had deposited. After the reef formation, the MS11 seamount had submerged in late Eocene or before that time, and the seamount had been laid under the pelagic environment. The formation of cobalt crust is assumed to have started after Paleocene time.

The drillings were conducted at the three sites of the margin of the summit of the MS11 seamount, and eight drillings were done at the area of the water depth of 1,900m to 2,100m. The average thickness of the cobalt crust of each site is 121mm to 145mm, and 132mm as the average of the summit. In the survey of 1998, the average thickness of the cobalt crust of each sampling site varied 2mm to 49mm, and quite thin compared with that of this year. From the results of this year, the samples of six drilling points out of eight have thickness over 100mm, and it is assumed that the development of cobalt crust with thickness of more than 100mm is expected at the area where exposure of cobalt crust develops at the summit of the seamount.

In order to understand the relation of thickness of cobalt crust with depths, the drilling of BMS03 site was carried out at the middle of the slope, and 160mm thick cobalt crust sample was collected. Equally, in the survey of 1998, the average thickness of 100mm was obtained at the AD09 site located on upper slope. Considering these two data, it is assumed that the cobalt crust with thickness more than 100mm is, also distributed in the slope area. As the results of examining the relation between the acoustic intensity distribution and the thickness of unconsolidated sediments, the followings are deduced. The cobalt crust develops at the area shown by dark tone in the acoustic image. The area, corresponding the boundary of dark tone and middle tone in the acoustic image, is overlain by unconsolidated sediments of the thickness of about 1meter. The thickness of unconsolidated sediments at the middle tone in the acoustic image attains greater than 1 meter. As the results of the drilling survey of this year, average grade of Co 0.34%, Ni 0.39%, Cu 0.12%, Mn 19.50%, Fe 15.01%, and the content

of Pt of 0.38ppm are obtained. Compared with that of the survey results of 1998, Co and Pt are low, and Cu is high.

4-1-1-3 MS12 Seamount

The MS12 seamount is an isolated table seamount, situated southeast of Anewetak Atoll with the water depth at the shallowest point of the summit of 1,037m, and relative height from the base to the summit of 3,900m. The area of exposed rock is distributed around the margin of the summit, and the distribution seems a little wider at the east and west of the summit.

A wide distribution of basalt is observed at the MS12 seamount and pyroclastic rocks develop at the south and northeast of the summit. The development of limestone is local and seems comparatively thin, suggesting the seamount had been submerged in early time. The basalt of the MS12 seamount is alkaline basalt formed under the environment of oceanic island in Middle Cretaceous. After the formation of the seamount, reef had been formed around the seamount but the seamount had submerged to the depth allowing the deposition of pelagic sediments. The main formation period of the cobalt crust is assumed to be in middle Eocene time and later.

The drilling survey was conducted at the seven sites in the area from the margin of the summit to the summit and cobalt crust samples were collected from all the drilling points. The average thickness of the cobalt crust at each site is 32mm to 93mm, and the average of the all sites is 70mm. In the survey result of 1998, the thickness of cobalt crust at the each sampling site of the summit area was 14mm to 34mm, and quite thin compared with that of this year. However, maximum thickness of the cobalt crust of 60mm and 95 mm were collected in the survey of 1998, the average thickness obtained from the results of this year seems appropriate. The drilling site selected for the survey of this year is the area at the margin of the summit to the summit area of the water depth of 1,150m to 1,380m. The difference of water depths of each drilling point is small, so that the examination of the relation of the thickness of cobalt crust with water depth could not be done. The horizontal continuity of cobalt crust was investigated at the dark tone area in the acoustic image. It was confirmed by six drillings along 3km long track line that the cobalt crust of thickness of 50mm to 120mm, average thickness of 90mm developed continuously. In order to understand the occurrence of cobalt crust under the sediments, the LC sampling was conducted at the point corresponds to the boundary of dark tone and light tone in the acoustic image, but the appropriate samples to estimate the thickness of the sediments and underlying crust could not be obtained. But even in the area correspond to the dark tone in the acoustic image, at the points covered by 5cm

to 15cm thick sediments, the thickness of the cobalt crust seems poor compared with that at the exposed point..

From the results of the drilling survey of this year, average grade of Co 0.46%, Ni 0.57%, Cu 0.05%, Mn 22.22%, Fe 11.41%, and the content of Pt 0.40ppm were obtained. Compared with the result of the survey of 1998, the grade of Co and Fe are low.

4-1-2 Ore Resources

On the basis of the results of the survey of this year, the inferred resources of the three seamounts, MS01, MS11, and MS12, were calculated. It is shown in Table 4-1-2-1. In the calculation, density of cobalt crust is estimated to be 2.0. The inferred resources of three seamounts are, in the order of abundance, 173.2 million ton, 55.5 million ton and 32.8 million ton for seamounts MS11, MS01 and MS12, respectively. The grades of Co, Ni and Pt are lowest in MS11 seamount, however, because the size is the largest with thickest cobalt crust, metal quantities are highest in MS11 seamount, Co 589,000 ton, Ni 693,000 ton and Pt65.8 ton. The metal quantities of MS01 and MS12 seamounts are Co 244,000 ton, Ni 360,000 ton, Pt 48.3 ton and Co 151,000ton, Ni 187,000 ton, Pt 13.1 ton, respectively. In this connection, the productions of Co, Ni and Pt of the world in 2000 are Co 28,300ton, Ni 1,045,600 and Pt 307ton.

4-1-3 Considerations

The survey of this year was carried out to understand the occurrence of cobalt crust at the summit area of three seamounts, MS01, MS11, and MS12, mainly by drilling. As the results, the average thickness of the cobalt crust at the each seamount is 59mm, 132mm, and 70mm. This is thick compared with the results of the previous year. On the contrary, the average grades of Co of the three seamounts are 0.44%, 0.34%, and 0.46% and they are low. This is attributed to the difference of sampling method. The reason for this is that dredge and LC samplings collected incomplete cobalt crust samples dominated by outer layer fraction during the survey of previous years. This is conformable with the result that the grade of Co of this year is lower than that of previous year. The grade of Co is higher at outer layer compared with inner layer. Concerning the thickness of cobalt crust, the maximum thickness of each site obtained by the dredging is close to the thickness of the drilling sample.

Table 4-1-2-1 Inferred Resources of Cobalt Crust

Seamount	Considered Water depth (m)	Total Area (k㎡)	Area Covered by Sediment	Exposed Area (k㎡)	Average Thickness of Cobalt Crust (mm)	Co(%)	Ni(%)	Pt (ppm)	Inferred Resources (million t)	Co Quantity (t)	Ni Quantity (t)	Pt Quantity (t)
MS01	summit～2,600	738	268	470	59	0.44	0.65	0.87	55.5	244,000	360,000	48.3
MS11	summit～3,000	1,238	582	656	132	0.34	0.40	0.38	173.2	589,000	693,000	65.8
MS12	summit～2,000	462	228	234	70	0.46	0.57	0.40	32.8	151,000	187,000	13.1

exposed area = total area - area covered by sediments.

inferred resources ＝ exposed area × average thickness × 2.0 (specific gravity)

Average thickness of summit area obtained by survey of this year was used for calculation.

4 - 2 Environmental Survey

An environmental survey was conducted to evaluate the potential magnitude of mining impacts in the deep-sea environment by investigating the distributions of benthic organisms (Meiobenthos and Macrobenthos) and properties of sediments（Total Organic Carbon and Total Nitrogen）.

The survey was conducted in three seamounts areas (MS12, MS11 and MS01). The sampling stations were at the top of the seamounts and on their slopes at different water depths.

General trends in the results from the three seamounts indicate that the abundance of metazoan meiobenthos decreases with increasing water depth. High concentrations of surface nematodes were remarkable in the vertical distributions. The abundance of metazoan macrobenthos decreased with increasing water depth as it did in the meiobenthos, and their high concentrations were remarkable in the surface layer. In the vertical distributions of the sediment properties, concentrations of the total organic carbon and the total nitrogen decreased with increasing sediment depth at some stations.

Generally speaking, the abundance of benthic organisms is mainly controlled by the quantity of available organic matter. This is supported by the finding in this study that benthic organisms decreased in abundance from the top of seamounts to the slope sites. This is because the quantities of organic matter, which reflect the feeding conditions of benthic organisms, are likely to accumulate at the top of a seamount and not on the seamount slopes. Then, there were differences in the abundances of benthic organisms in each seamount area It is also reasonable to assume that differences in topography influence heterogeneity in feeding conditions for the benthic organisms. It suggests necessity of survey for relationship of the topography and the accumulation pattern of organic materials in the future.

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