No. 13

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

(VOLUME 4-1)

SEA AREA OF THE REPUBLIC
OF THE MARSHALL ISLANDS

March 1999

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

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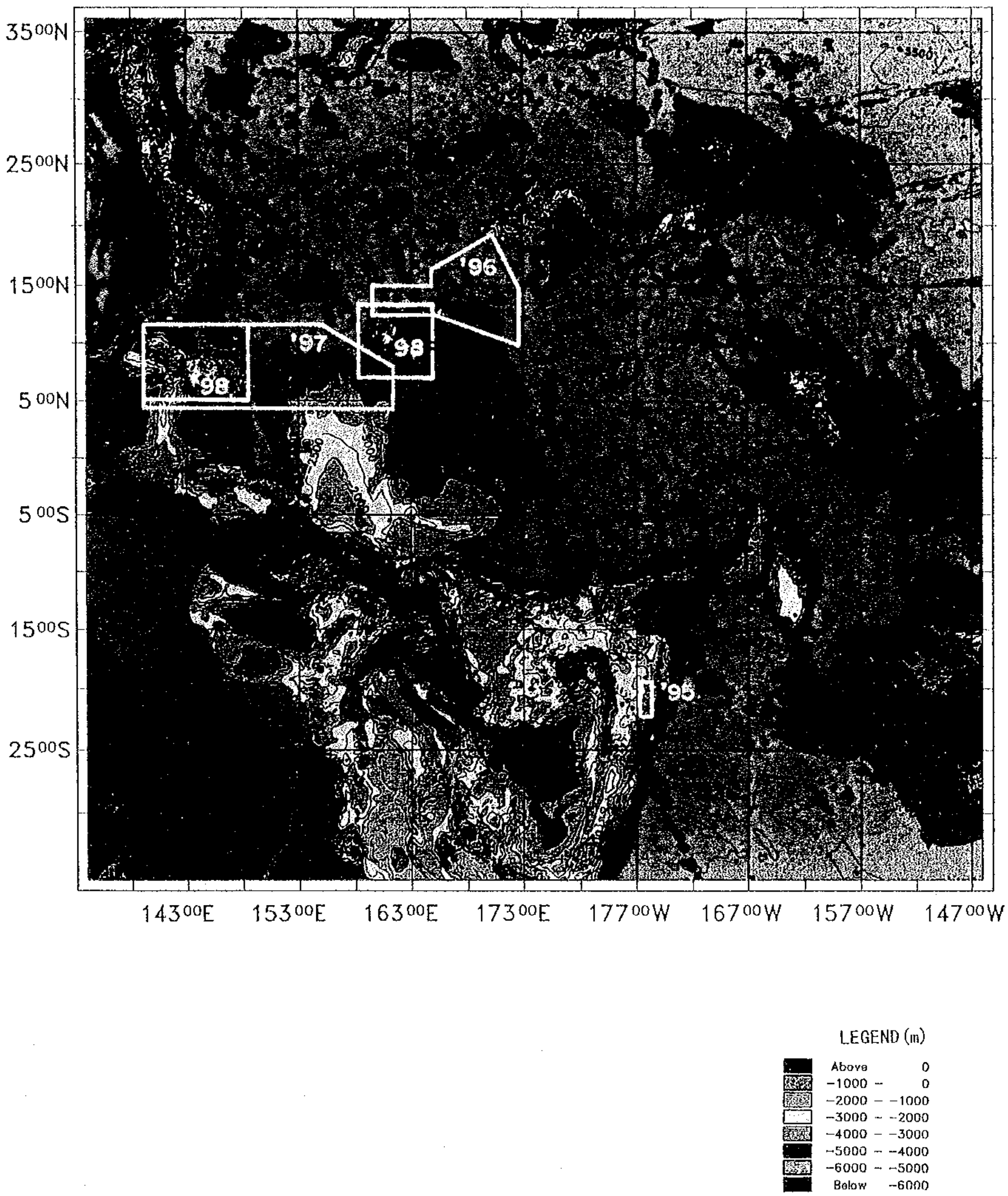
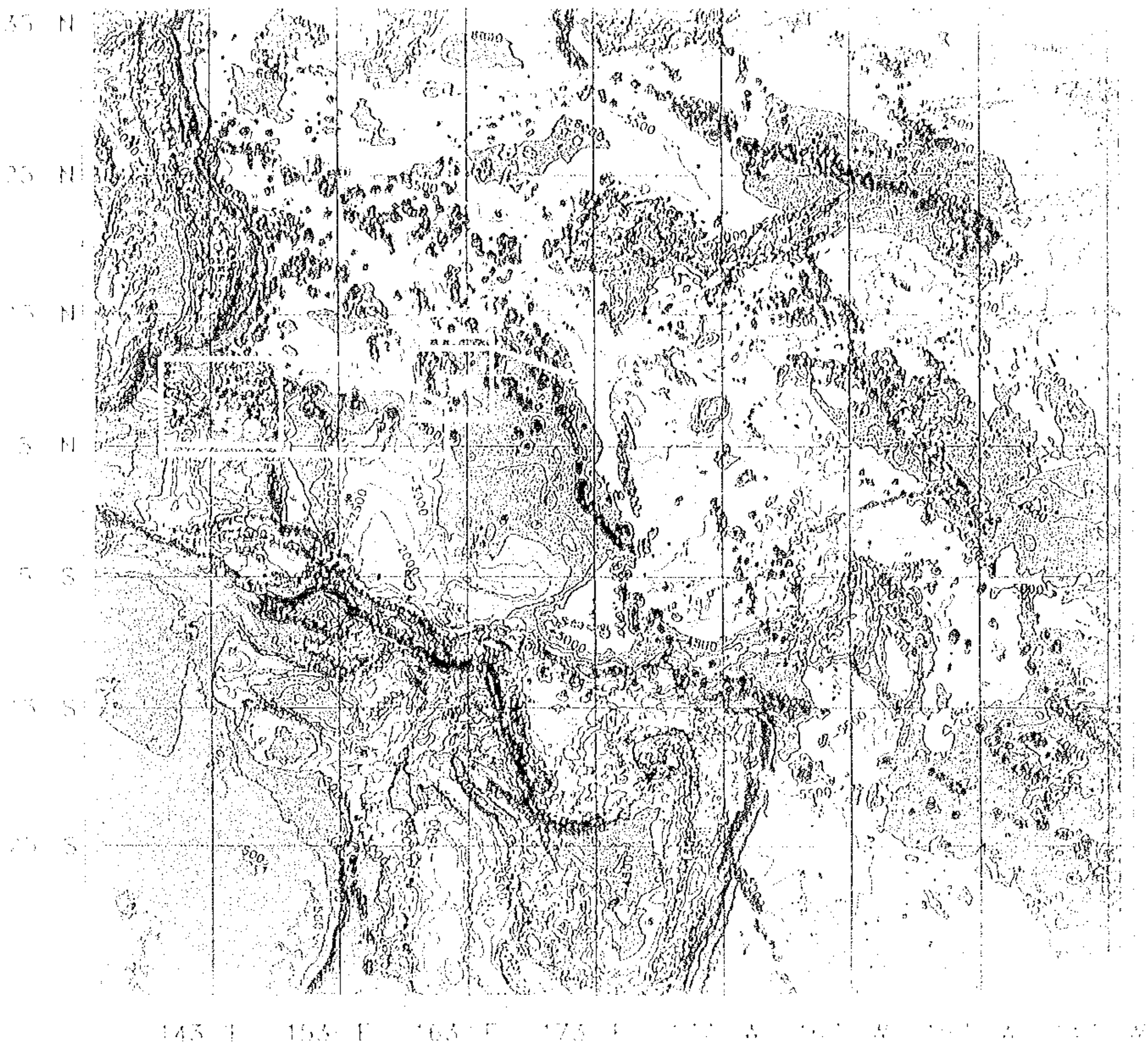


LOCATION MAP OF THE SURVEY AREA



LOCATION MAP OF THE SURVEY AREA

PREFACE

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

The survey is planned to be undertaken over a period of five years starting from Fiscal 1995. This is the fourth year of the project, and the target area is the exclusive economic zones of the Republic of the Marshall Islands and the Federated States of Micronesia. MMAJ dispatched the Hakurei Maru No.2, a research vessel fitted for investigating deep sea mineral resources, to the survey area from May 5, 1998 to July 17, 1998, successfully completing the survey as planned with the cooperation of both government. The survey in the Exclusive Economic Zone of the Federated States of Micronesia was carried out during the periods from May 28th, to May 30th, and from June 14th to July 2nd.

The present report sums up the results of this fourth year survey in the Exclusive Economic Zone of the Federated States of Micronesia.

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

March, 1999

Kimio FUJITA
President
Japan International Cooperation Agency

Hiroaki HIYAMA
President
Metal Mining Agency of Japan

Abstract

The third phase of the cooperative survey for the development of resources of the SOPAC member countries is being scheduled for implementation during a period of five years starting from 1995, and this is the fourth year. The survey for this year was carried out from May 5 to July 17, 1998 in an area of 1,265,000km^2 in the exclusive economic zones of the Republic of the Marshall Islands and the Federated States of Micronesia. The duration of the survey was 49 days and the target mineral resources were cobalt-rich manganese crust deposits.

The occurrence of cobalt-rich crusts in the exclusive economic zone of the Republic of Marshall Islands was surveyed in Fiscal 1996, and those in the exclusive economic zone of the Federated States of Micronesia in Fiscal 1997. This year, based on the results obtained by the earlier surveys, similar work was carried out in the unexplored parts of the EEZ of the two countries with the purpose of acquiring further information and data on these resources.

The survey area consisted of two marine areas, namely the eastern sea area centered around the oceanic plateau with Anewetak Atoll and Ujelang Atoll of the Republic of Marshall Islands, and the western sea area in the vicinity of the Caroline Islands of Yap Province of the Federated States of Micronesia. A total of eight areas were selected; namely for Leg 1 in the first half of the cruise, five seamounts in the eastern sea mainly in the EEZ of the Marshall Islands, and for Leg 2 in the latter half, two seamounts for cobalt crust investigation and one area for hydrothermal activities in the western sea of the Micronesia EEZ were planned to be surveyed.

In the EEZ of the Marshall Islands, three to four belts of oceanic islands and seamounts are distributed centered around atoll chains called Ralik Chain and Ratak Chain. In 1996, seamounts in the northern part joined to the Ralik and Ratak Chains were surveyed, and the occurrence of cobalt-rich crusts was confirmed. This year, five seamounts connected to the Magellan Seamount Group with center in Anewatak and Ujelang Atolls were surveyed. These are located to the southwest of the area surveyed in 1996. Occurrence of cobalt-rich crust deposits was confirmed in all the seamounts surveyed.

This paper reports the results of the cobalt-rich crust exploration carried out this year in the four marine areas of the EEZ of the Republic of Marshall Islands.

The seamounts for the survey were selected considering; the water depth of the summit (targeting 1,000~2,000m water depth where crusts are considered to be well developed), morphology, and size, and other relevant factors as necessary. Satellite Altimetry Data by Sandwell et al., (1997) was used in the selection.

The survey cruise for cobalt-rich crust investigation consisted mainly of; MBES survey (topographic cruise) for clarifying the detailed topography of each area, seafloor observation by FDC and photography for confirming the

continuity of the ore deposits, and sampling by chain bag dredge (CB), arm dredge (AD), and large corer (LC) for understanding the mode of occurrence of the crusts such as type, thickness, and grade. Parts of the collected samples were assayed, examined by X-ray diffraction, rocks studied by thin section microscopy, and other relevant tests were made on land. These results, together with the results of the onboard work, were used for integrated analysis and interpretation of the cobalt-rich crust occurrences in the survey area. Also parallel with MBES, SBP survey was carried out in order to clarify the distribution of unconsolidated sediments, and SSS survey was conducted in some seamounts for the study of microtopography of the seafloor and nodule and pebble distribution.

Topographic survey was carried out in four areas of the eastern sea confirming four seamounts by clarifying the detailed seafloor topography. The surveyed seamounts were all guyots; two dome-type, one flat summit, and one rugged summit seamount.

The acoustic pressure maps prepared on the basis of MBES acoustic reflection intensity were very effective in understanding the lateral areal extent of exposed bedrock. These maps clarified the conditions of bedrocks exposures at protrusions such as pinnacles, summit peripheries, and steep slopes. Also the SSS survey, by applying more detailed acoustic pressure distribution, clarified the microtopography and the distribution of rock exposures, cobbly material and other relevant matters.

From seafloor observation by FDC, the mode of occurrence of cobalt-rich crusts of each seamount was confirmed. Particularly, the continuity of distribution, type, and shape of crusts, and the distribution of unconsolidated sediments and talus, and their relation to microtopography were clarified. The FDC observation clarified that cobalt-rich crusts are attached to the exposed rocks on the pinnacles, from the summit peripheries to the upper slopes of the seamounts.

Sampling was carried out at, 13~18 sites for each area, a total of 61 sites in four areas. Rocks with crusts attached, surface crusts, and bottom sediments such as foraminiferal sands were collected. The collected cobalt-rich crusts samples were described as to their weight, type, and thickness. These were assayed, fossils in limestones and foraminiferal sands identified, basalts were chemically analyzed and age determined on land.

The area surveyed including that of 1996 comprise the northwestern half of the EEZ of the Marshall Islands. The seamounts and the occurrence of the cobalt-rich crusts in this area are summarized as follows.

Pointed seamount was surveyed in only one area in the easternmost part of the 1996 survey area. Cobalt content is relatively high and the seamount is characteristically young (35Ma).

Most of the seamounts in 13 areas surveyed were guyots, and they are further classified into six dome-type, four flat, and two rugged-summit type seamounts. Area-wise, the flat and rugged types occur on east and western parts of the area and dome-type seamounts are distributed in the central part. The thickness of the SBP transparent layers, which indicate the unconsolidated sediments on the summits, tends to be thin on flat seamounts and thick on dome types.

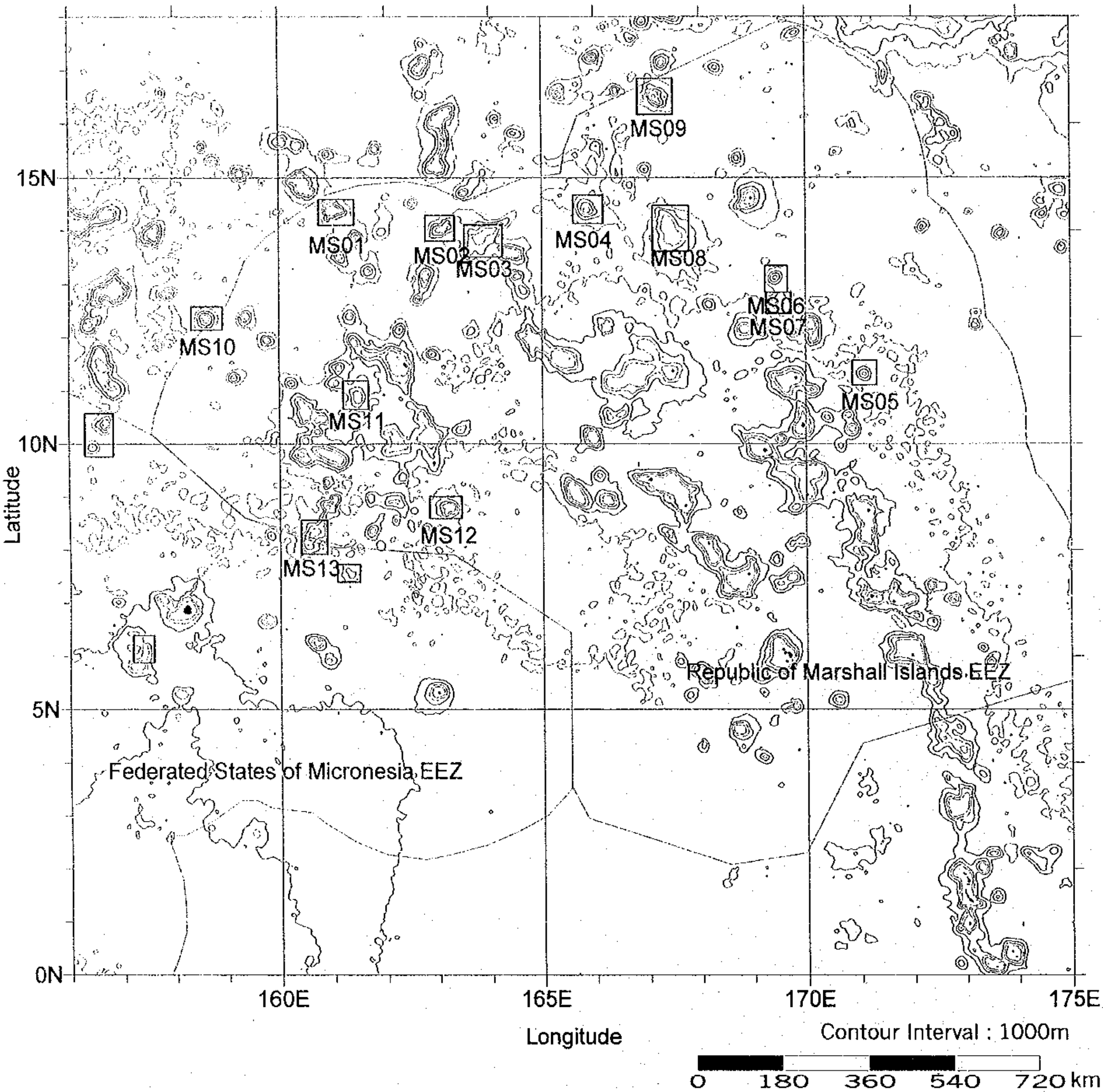
Sampling results and seafloor observation revealed that crusts with thickness exceeding 10cm occur at water depth of 1,000~3,500m. Cobalt-rich crusts occur as crusts, cobbles, and nodules, and their thickness varies mainly with area, topography, and substrate. The average thickness of the cobalt-rich crusts is thick in the west and the cobalt content, although not very clear, tends to be higher to the east.

These seamounts are considered to be older than Paleogene and relatively thick and higher grade cobalt-rich crusts generally occur on them.

Assessing the areas on the basis of crust occurrences, the seamounts in the western sea are the most promising within this year's survey area in the EEZ of the Marshall Islands. This part is followed by the seamounts continuous to the northern part of Ratak Chain in the eastern part of the EEZ. This assessment is reached by the fact that crusts are thick in the western seamounts and the cobalt grade is high in the crusts in the eastern side.

Although reliable data are few, it is inferred, from available information including those of the vicinity, that the seamounts of the Ratak, Ralik, Anewetak - Magellan Chains and Groups become older to the north or west. Also regarding the thickness of the layers of the crusts, the base layer tends to thickens with age, and the cobalt content tend to increase toward the surface layer. It is might be possible to explain the trend of the mode of occurrence of the cobalt-rich crusts of the EEZ of the Republic of Marshall Islands by the above line of facts.

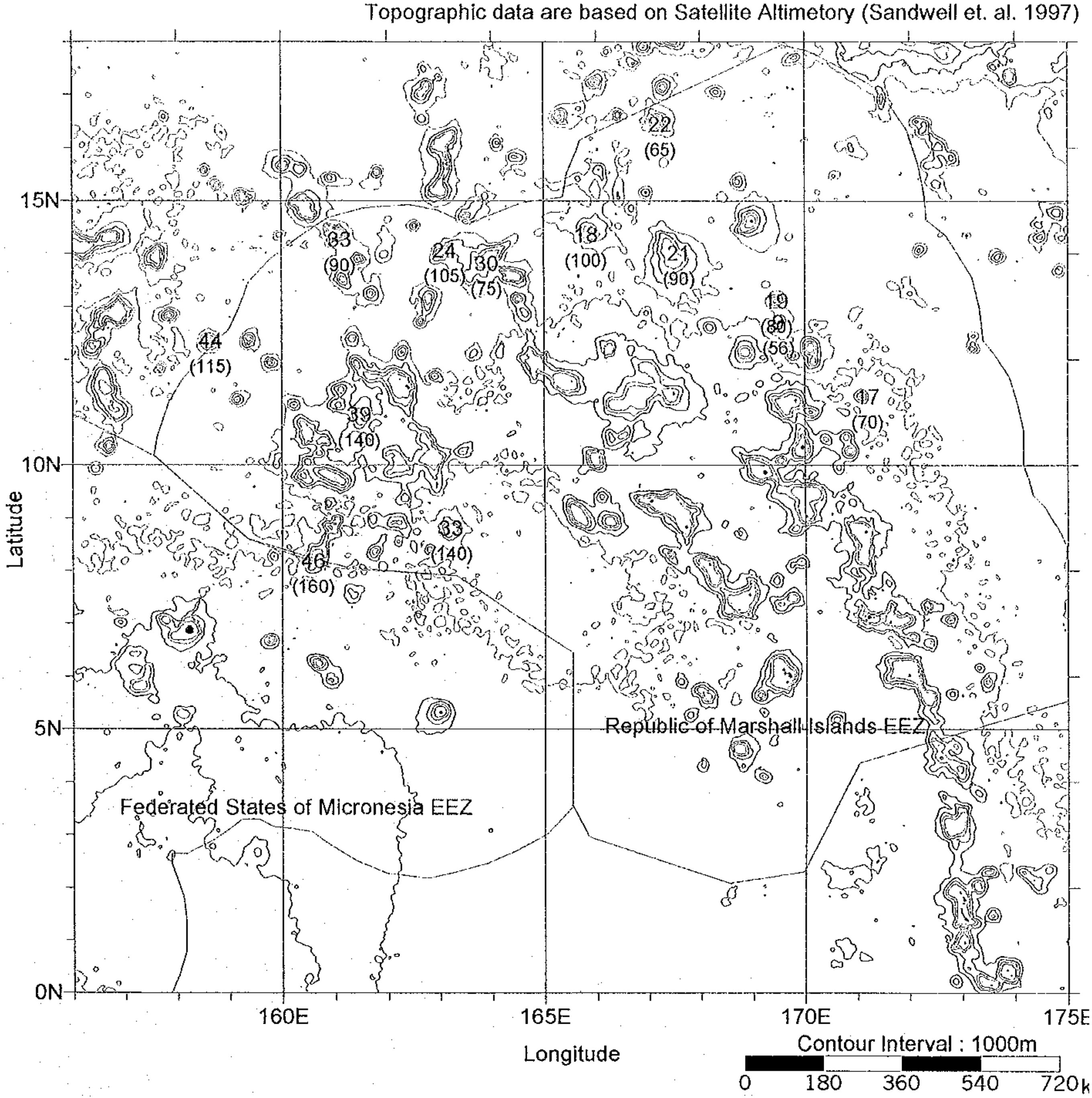
Topographic data are based on Satellite Altimetory (Sandwell et. al. 1997)



Name of Prospected Area

Prospected in '98

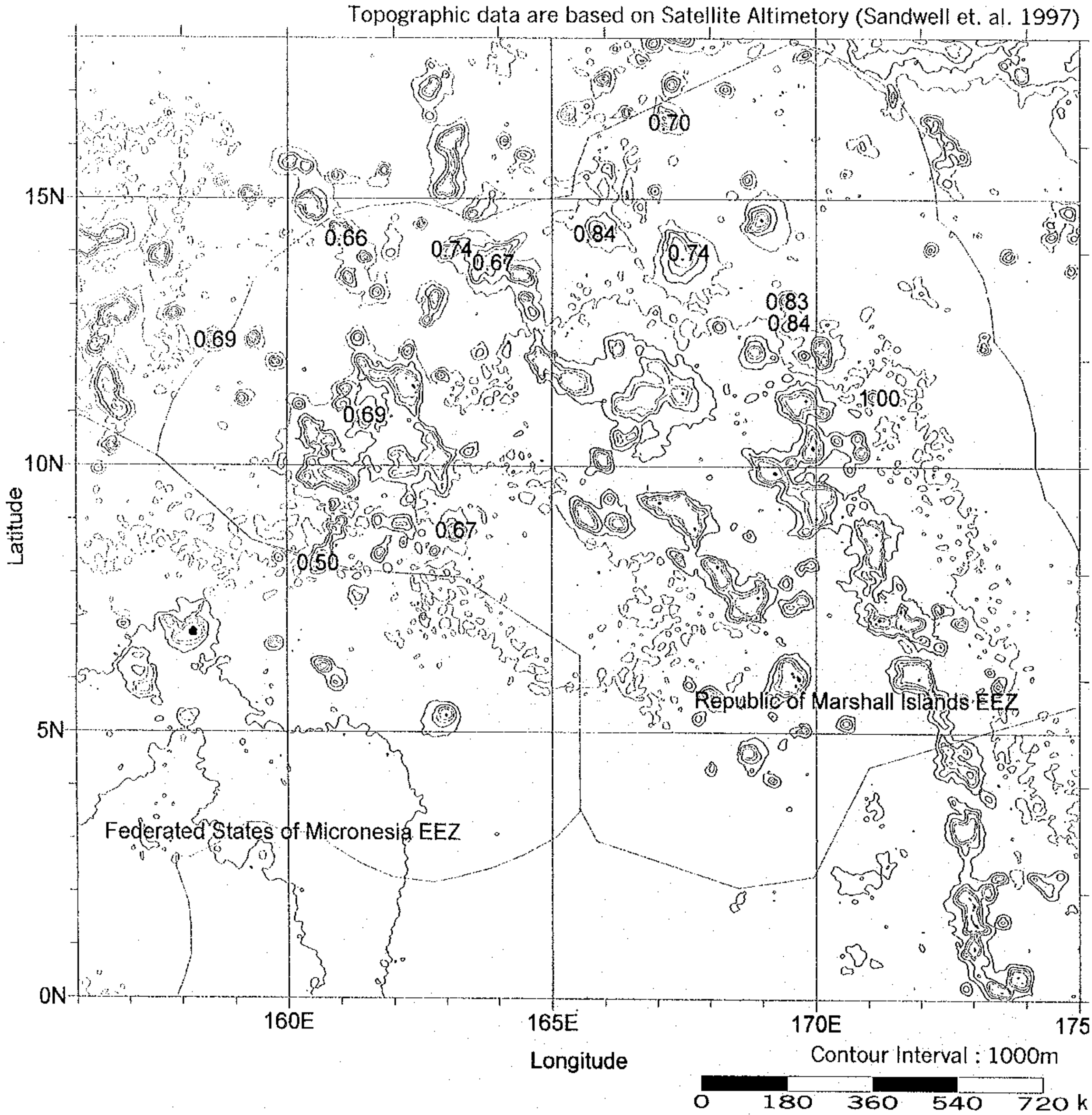
Prospected in '96



Average Thickness of Crust

(Maxmum Thickness of Crust)

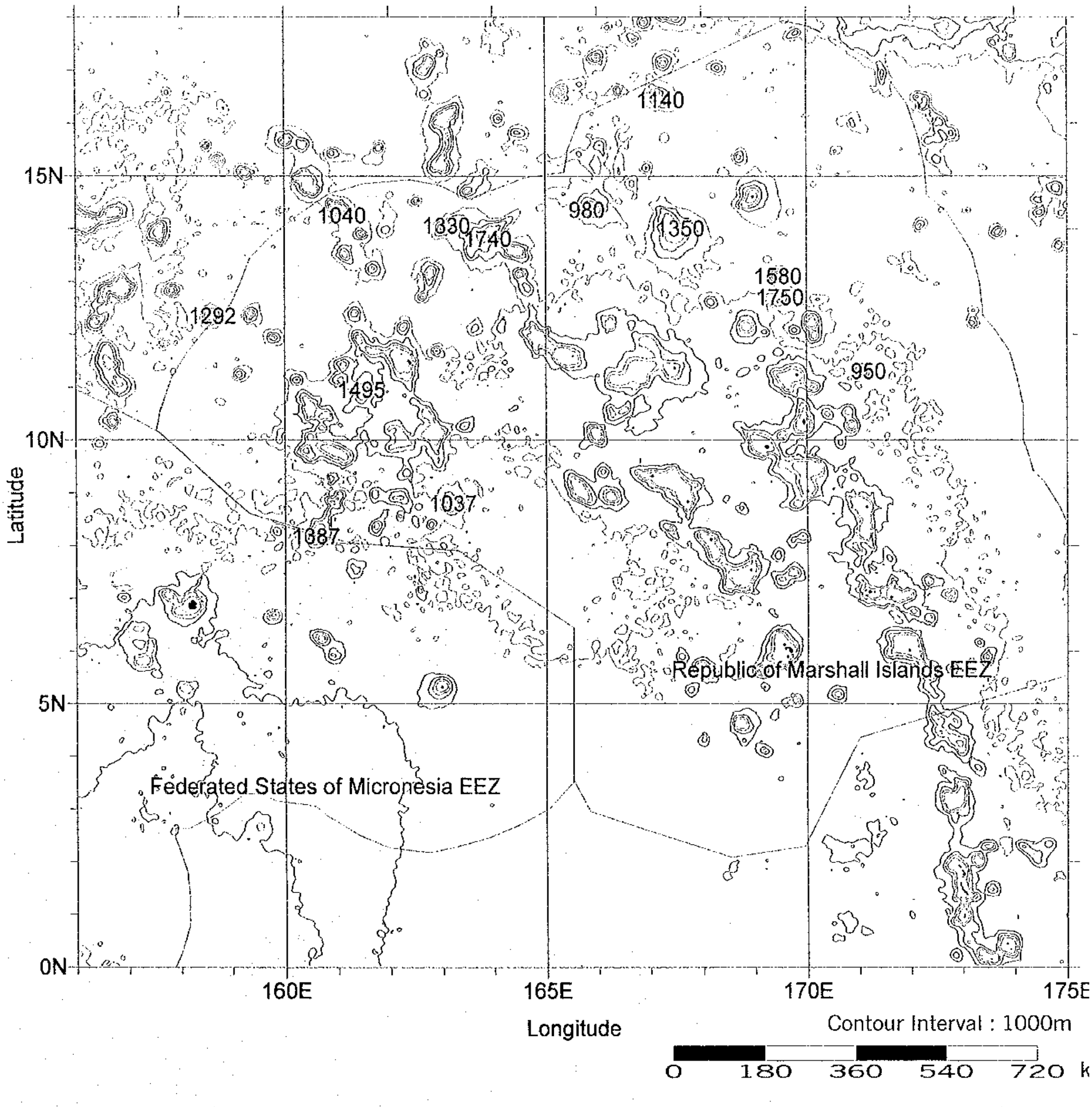
(unit mm)



Average Co. Contents.

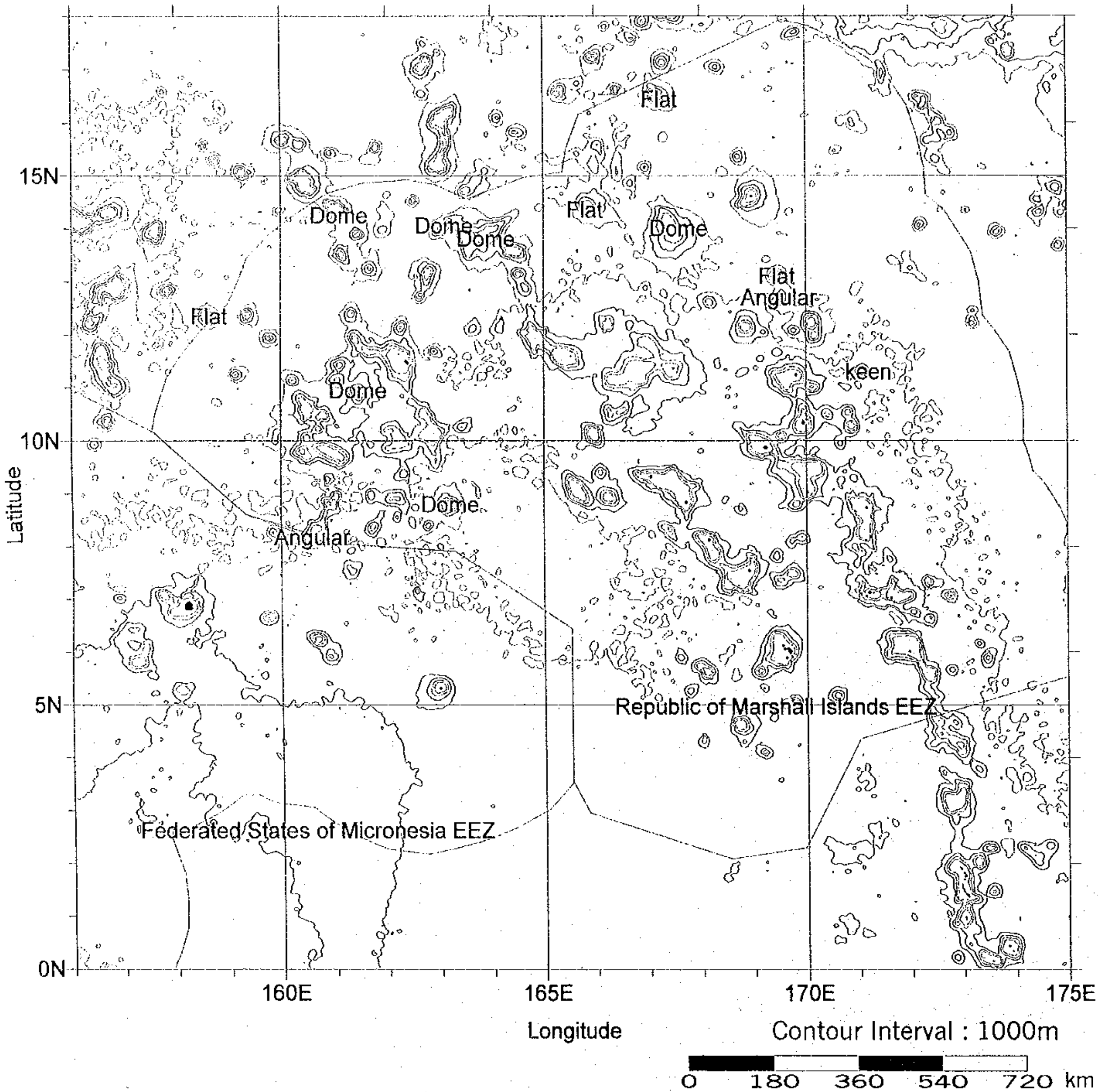
(%)

Topographic data are based on Satellite Altimetory (Sandwell et. al. 1997)

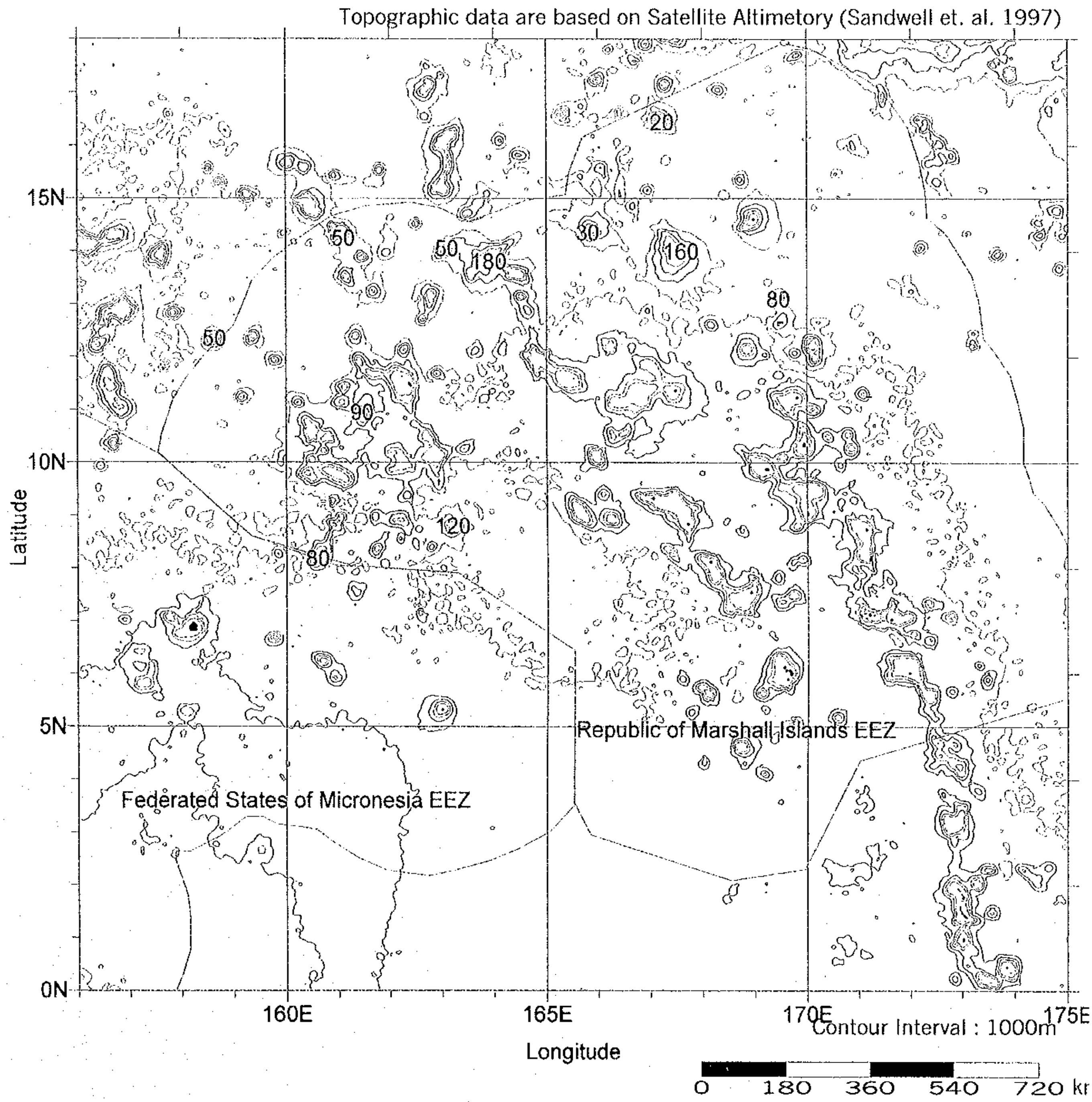


Shallowest Depth of Seamount.

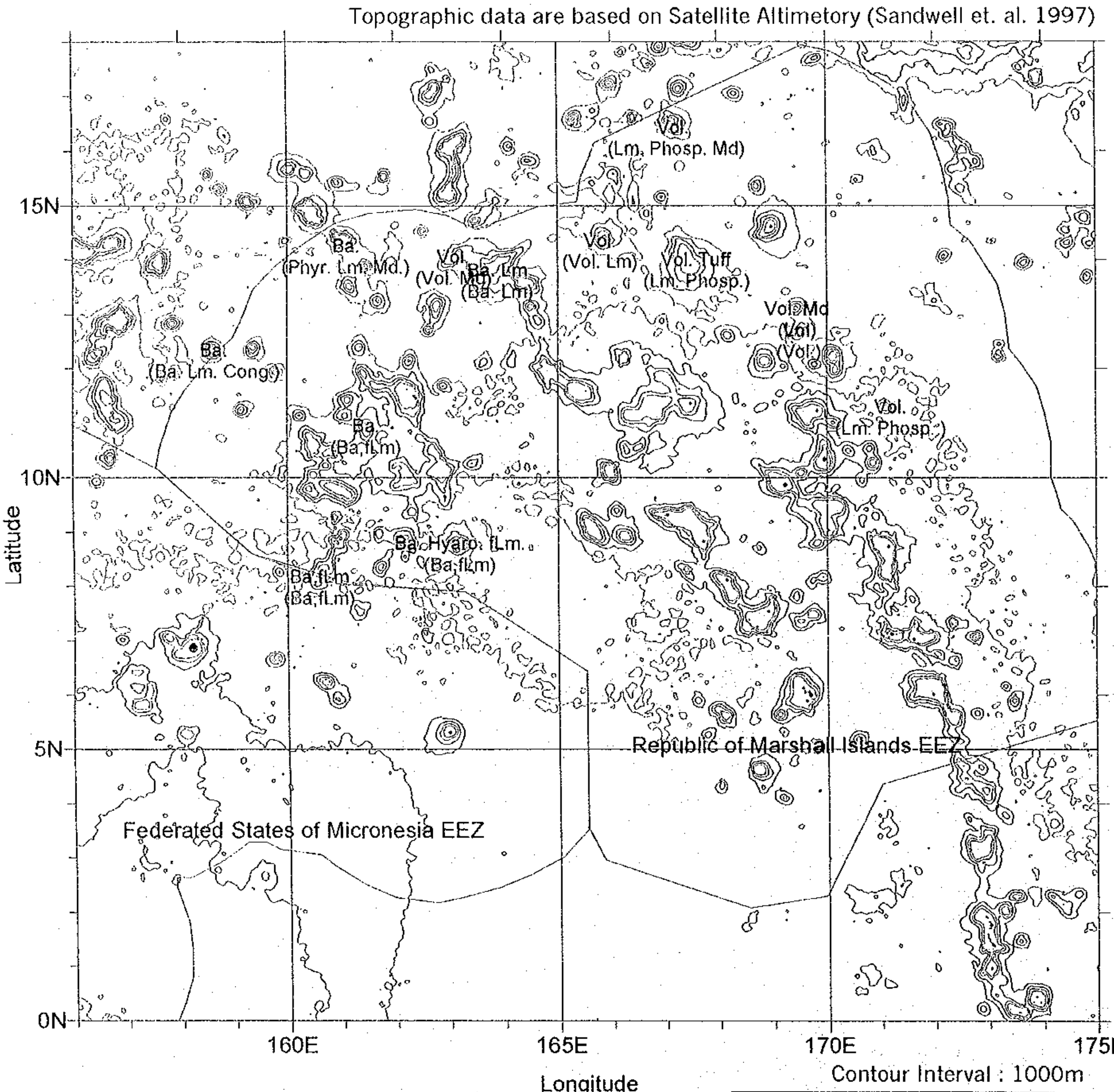
Base Map: ETOPO5



Shape of Summit



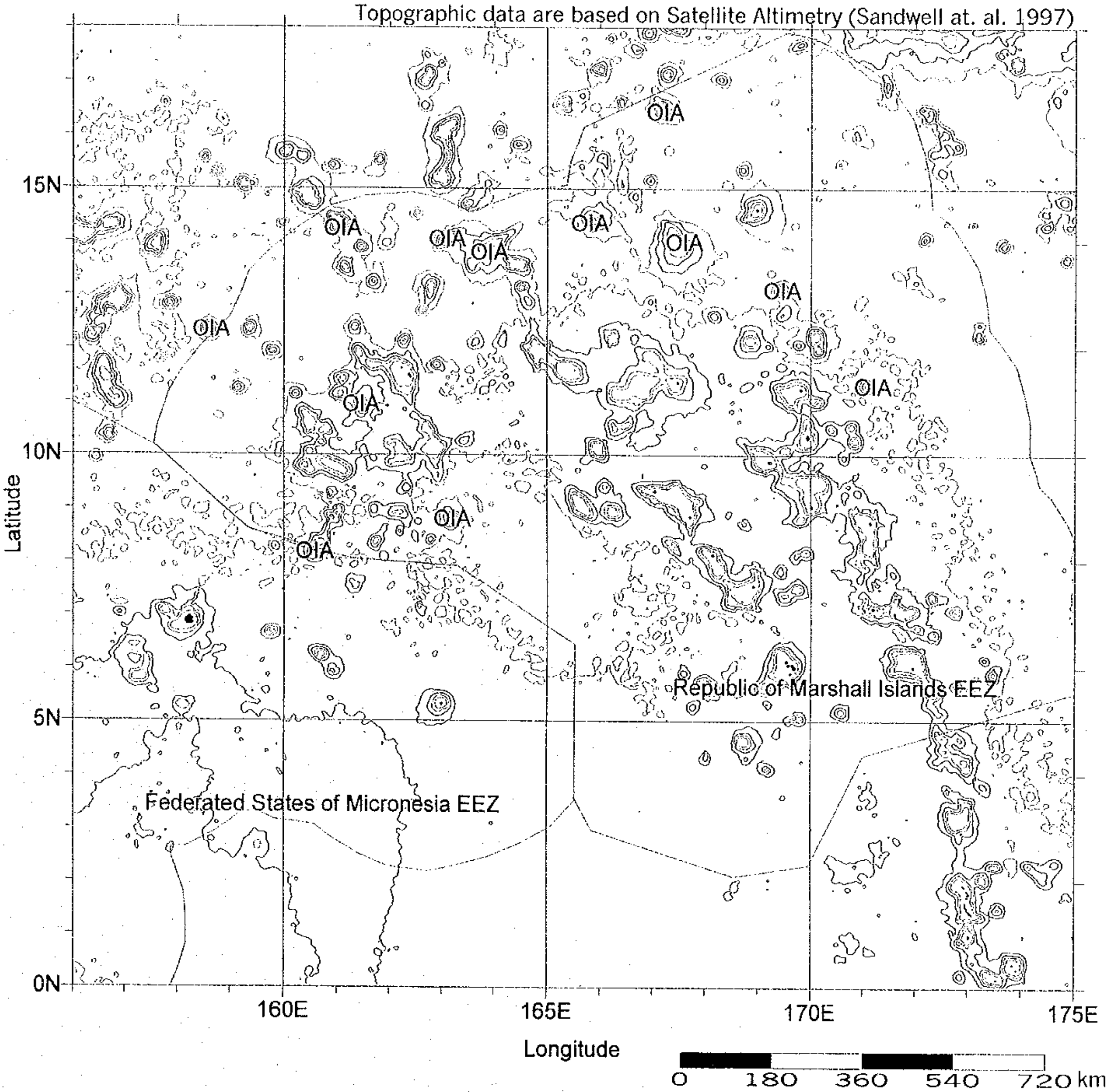
Thickness of SBP Transperency Layer. (m)



Geeology(Summit)

Geology(Slope)

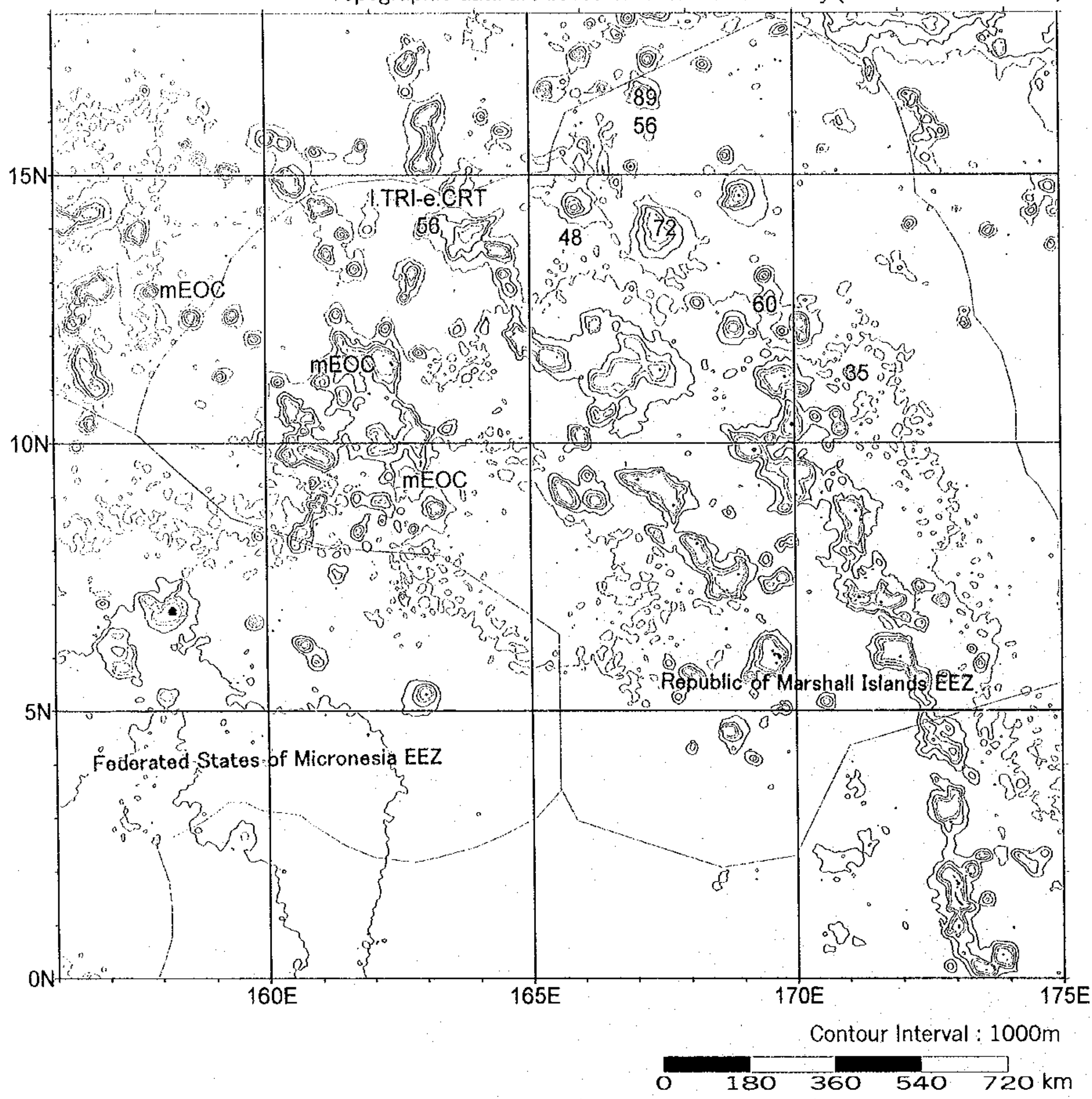
Ba Basalt.
Vol Volcanic Rock
Phyr Phyroclastic Rock
Lm Limestone
fLm forminifera Limestone
Phosp Phosphorite
Md Mudstone
Hyaro Hyaroclastite



Type of Basalt.

OIA Ocean Island Alkali-Basalt

Topographic data are based on Satellite Altimetory (Sandwell at. al. 1997)



Age of Fossils

Age of Basalt (Summit).

Age of Basalt (Slope)

(unit Ma)

CONTENTS

[List of Inserted Figures]

[List of Inserted Tables]

Chapter 1 Outline of the Survey

1 - 1 Survey Title

The Cooperative Study Project on the Deepsea Mineral Resources in Selected Offshore Areas of the SOPAC Region, 1998

---- Sea Area of the Republic of Marshall Islands and the Federated States of Micronesia ----

1 - 2 Purpose of the Survey

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

1 – 3 Survey Area

The survey areas for this study are the areas within the polygons obtained by joining the following coordinates (approximately 551,793km² in the eastern sea area, and 712,683km² in the western sea area, Figs.1-3-1). These areas were selected in accordance with the joint study program for marine mineral resources in the exclusive economic waters of the SOPAC member countries agreed upon by the Japanese executing agency and the South Pacific Applied Geoscience Commission (SOPAC) on 13 March 1995.

Eastern Area			Western Area		
No.	Latitude	Longitude	No.	Latitude	Longitude
A.	13° 30' N,	158° 00' E	A.	11° 30' N,	139° 00' E
B.	13° 30' N,	165° 00' E	B.	11° 30' N,	148° 00' E
C.	7° 00' N,	165° 00' E	C.	5° 00' N,	148° 00' E
D.	7° 00' N,	158° 00' E	D.	5° 00' N,	139° 00' E
A.	13° 00' N,	158° 00' E	A.	11° 30' N,	139° 00' E

1 - 4 Duration of the Survey

Survey cruise: May 5 to July 17, 1998 (49 days)

Analysis and other work: April 1, 1998 to March 31, 1999

1 - 5 Survey Participants

			(period)
Japanese participants			
Field supervisor :	Akira USUI	(Geological Survey of Japan)	(5/3～6/9)
Members:			
Leader	Kohei MAEDA	(Deep Ocean Resources Development Co., Ltd. : DORD)	(5/3～7/18)
	Kiyoshi TONO	"	(5/3～7/18)
	Nadao SAITO	"	(5/3～7/19)
	Nobuyuki MURAYAMA	"	(5/3～7/20)
	Masatsugu OKAZAKI	"	(5/3～7/21)
	Kazunori MATSUI	"	(5/3～7/22)
	Takayoshi KODAMA	"	(5/3～7/23)
	Junzo YOSHIWAKA	"	(5/3～7/24)
	Hiroyuki II	"	(5/3～7/25)
	Takehiro BUTO	"	(5/3～7/26)
	Tadashi SATO	(Ocean Engineering & Development Co., Ltd. : OED)	(5/3～7/18)
	Takao SAITO	"	(5/3～6/9)
	Iori ONIZUKA	"	(6/18～7/18)
	Yutaka HASHIMOTO	"	(5/3～6/9)
	Shinji MARUYAMA	"	(5/3～7/18)
	Nobuhiro YAMAMOTO	"	(6/10～7/18)
	Masashige OKADA	"	(5/3～7/18)
	Yoshihiro HATANAKA	"	(6/10～7/18)
	Kou ITO	"	(5/3～7/18)
	Yukari SHIMIZU	"	(5/3～6/9)
Consigned Participants			
Trainee:	Mr. Andrike Albert	(Republic of the Marshall Islands)	(5/5 ~ 6/8)

1 - 6 Survey Apparatus and Equipment

Major apparatus and equipment used during the survey are shown in Table 1-6-1 and Figure 1-6-1.

1 - 7 Survey Achievements

Survey operations were accomplished as shown in Tables 1-7-1 and 1-7-2.

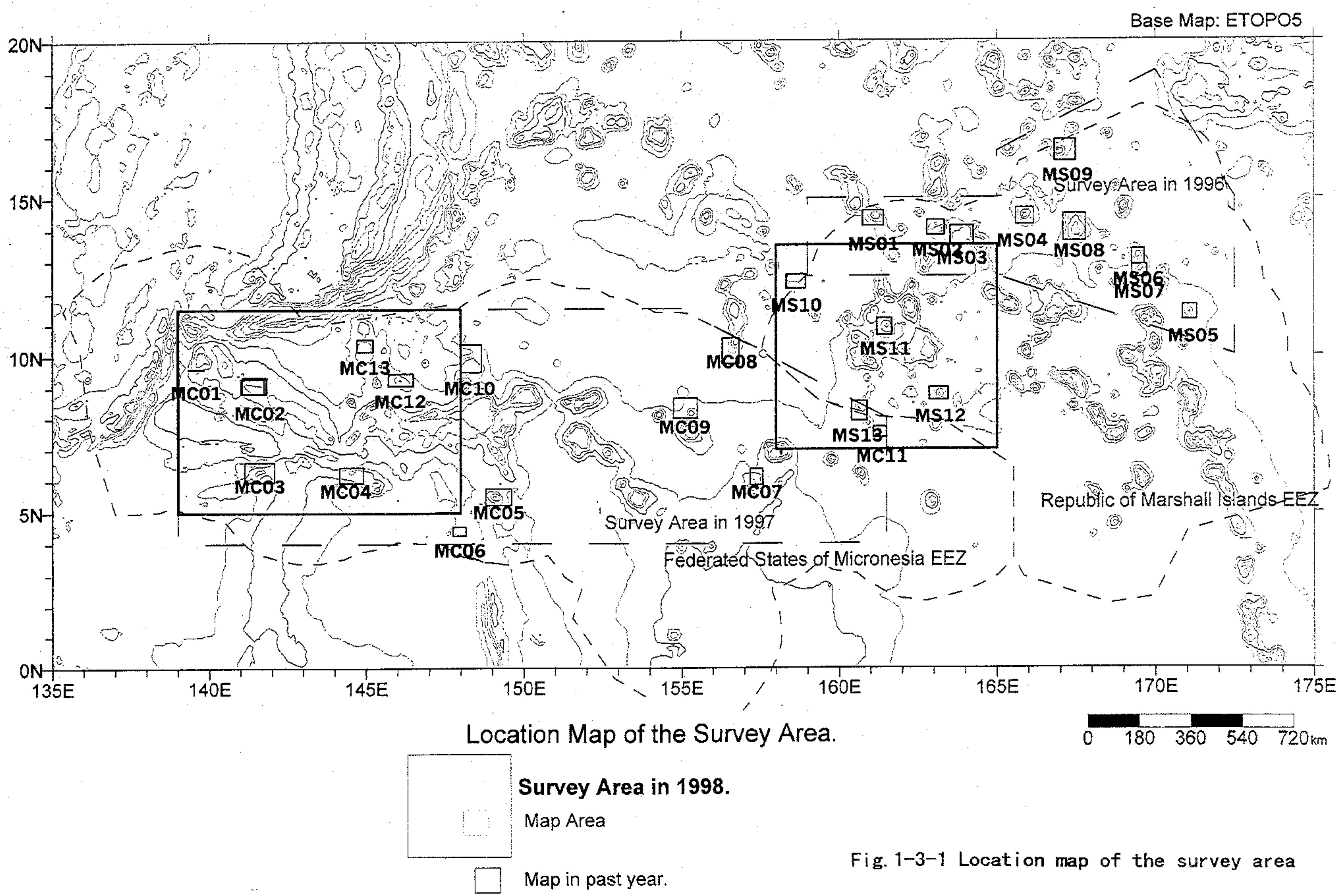


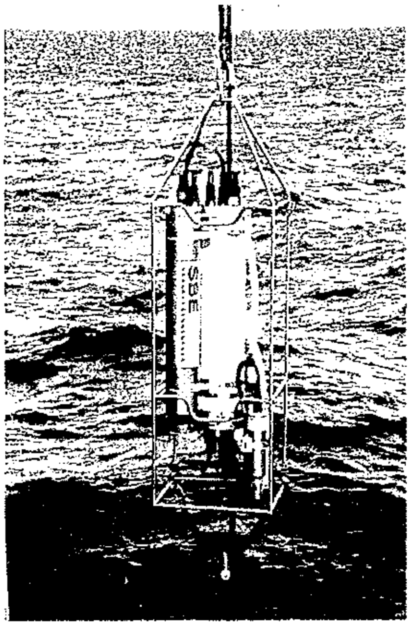
Fig. 1-3-1 Location map of the survey area

Table 1-6-1 Survey apparatus and equipment

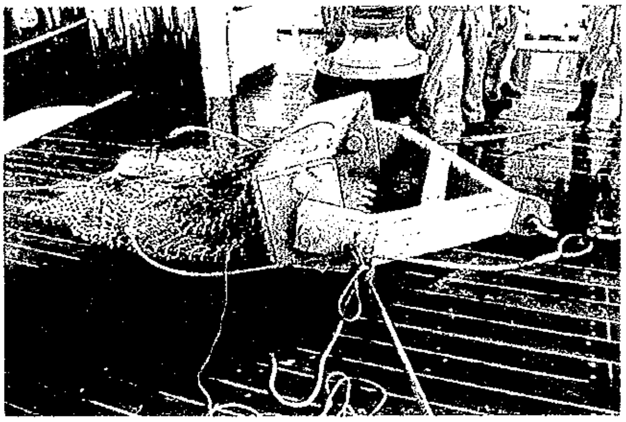
	Survey Method	Survey Apparatus and System	Abbre-viation	Remarks
Positioning	Satellite navigation	Global Positioning System	GPS	
Sea Bottom Topography and Geological Survey	Acoustic Sounding Bathymetry	Multi-narrow Beam Echo Sounder	MBES	
		Narrow Beam Echo Sounder	NBS	
	Subsurface Geological Structure	Narrow Beam Sub-Bottom Profiler	nSBP	
		Side Scan Sonar	SSS	Towed Type
	Seawater Survey	Conductivity, Temperature and Pressure measuring System	CTD &TD	Vertical type and Towed type
	Sampling	Chain Back Dredge	CB	
		Arm Dredge	AD	
		Large Gravity Corer	LC	
Seafloor Observation	Photograph and TV	Continuous Deep Sea Camera With Finder	FDC	with CTD Towed Type
	Photograph	Deep Sea Camera		with LC
Data Recording and Processing	On-Line Functions	Data Processing System		
	Data Storage Functions	Sensor CPU･File Server CPU		
	Off-Line Functions	Host CPU		
	↓	Engineering Work Station (EWS)		
	Track Line Maps	Local Area Network (LAN)		
	Various Plan Maps	Personal Computer (PC)		
	Cross Sections	Intelligent Color Monitor (ICM)		
	Data Analysis			

Table 1-7-1 Survey achievements

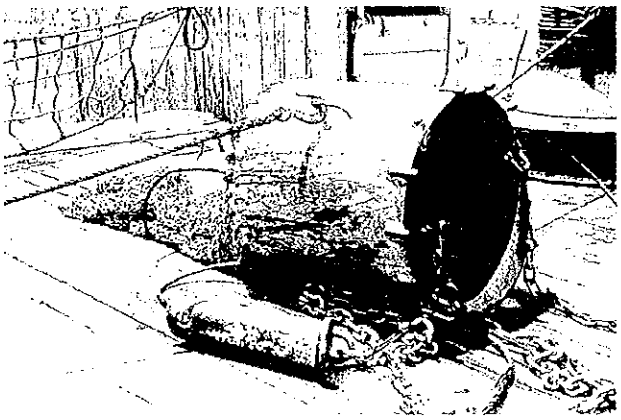
Survey Schedule						
Departure from Guam		5/5 16:00				
Start of SOPAC survey		5/8 23:00				
Finish of SOPAC survey		6/6 21:19				
Arrival at Pohnpei		6/8 9:00				
Departure from Pohnpei		6/12 8:00				
Start of SOPAC survey		6/14 20:00				
Finish of SOPAC survey		7/2 20:00				
Arrival at Guam		7/17 9:00				
Total days of survey		49 days (MS area 27days)				
Survey districts		4 districts	MS10	MS11	MS12	MS13
Number of sampling sites		61 sites	15	13	18	15
Kind of sampler	AD	45 sites	12	6	15	12
	CB	4 sites	--	4	–	–
	LC	12 sites	3	3	3	3
Amount of sampling		1,889 kg	264	69	732	824
Crusts		633 kg	18	6	200	409
Cobble crusts		661 kg	115	19	327	200
Nodules		28.4 kg	0.2	0.2	4	24
Rocks		346 kg	51	2	138	155
Sediments		221 kg	80	41	64	36
Seafloor observation						
FDC Number of track line		6 lines	1	1	2	2
Length of track lone		14.2 nm	2.5	3.2	4.6	3.9
Number of photos		656 sheets	150	142	172	192
Number of tapes		11 reels	2	2	3	4
Acoustic survey						
Length of track lines MBES·NBS		2,604.6 nm	599.1	587.8	572.7	845.0
Length of track lines SSS		24.7 nm	5.1	6.9	7.3	5.4



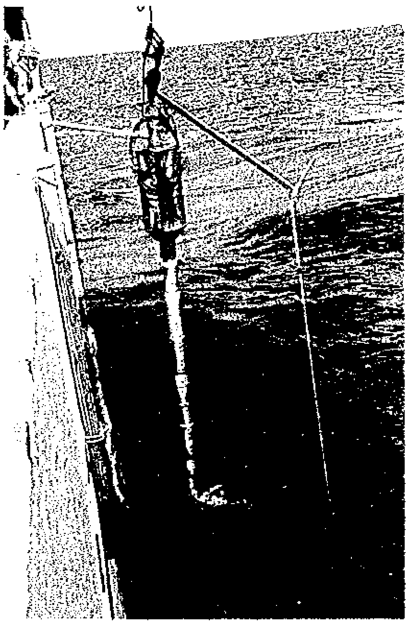
Conductiuity,Temperature and Depth Measurement System



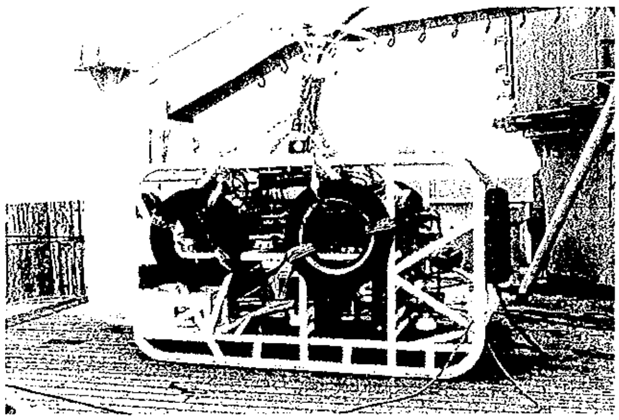
Arm Dredge



Chain-back Dredge



Large Gravity Corer



Deep Sea Towed Camera

Fig. 1-6-1 Photographs of main survey equipments

Table 1-7-2 Records of survey schedule

	Month/Day		Survey Item	Bathymetric survey	Area	Remark
	5/5	Tu	Departure from Guam			
	5/6	We				
	5/7	Tu				
1	5/8	Tu		127.2		23:00 Start
2	5/9	Fr	ctdLC01	113.4	MS10	
3	5/10	Sa	AD02,03,04,05	95.9	MS10	
4	5/11	Su	AD06,07,08,09	93.9	MS10	
5	5/12	Mo	AD10,11,12	71.9	MS10	
6	5/13	Tu	FDC01,LC13,14	96.8	MS10	
7	5/14	We	SSS01,AD15		MS10	17:00 Moving to MS11
8	5/15	Tu	ctdLC01	168.3	MS11	08:00 Start
9	5/16	Tu	AD02,03,04	109.3	MS11	
10	5/17	Fr	AD05,06,07	119.5	MS11	
11	5/18	Sa	AD08,09,10	93.3	MS11	
12	5/19	Su	FDC01,LC11,12	97.4	MS11	
13	5/20	Mo	SSS01,AD13	39.6	MS11	17:00 Moving to MS12
14	5/21	Tu	ctdLC01	173.3	MS12	08:00 Start
15	5/22	We	AD02,03,04,05	119.2	MS12	
16	5/23	Tu	AD06,07,08,09	112.0	MS12	
17	5/24	Tu	AD10,11,12,13	86.1	MS12	
18	5/25	Fr	SSS01,LC14	42.5	MS12	
19	5/26	Sa	FDC01,LC15		MS12	
20	5/27	Su	AD16,17,18	57.6	MS12	15:00 Moving to MC11
21	5/28	Tu	ctdLC01	172.3	MC11	01:00 Start
22	5/29	Fr	AD02,03,04	80.7	MC11	
23	5/30	Sa	AD05,06 FDC01	89.4	MC11	18:00 Moving to MS13
24	5/31	Mo	ctdLC01	172.8	MS13	09:00 Start
25	6/1	Tu	AD02,03,04	125.0	MS13	
26	6/2	We	AD05,06,07	121.9	MS13	
27	6/3	Tu	AD08,09,10	106.6	MS13	
28	6/4	Tu	SSS01 LC11,12	87.2	MS13	
29	6/5	Fr	FDC01,02	102.8	MS13	
30	6/6	Sa	AD13,14,15	39.3	MS13	22:19 Finish
	6/7	Su				
	6/8	Mo	Arrival in Pohnpei･Mid Leg Meeting			
	6/9	Tu				
	6/10	We				
	6/11	Tu				
	6/12	Tu	Departure from Pohnei			
	6/13	Fr				
31	6/14	Sa		123.4		20:00 Start
32	6/15	Mo	ctdLC01,AD02	166.7	MC12	
33	6/16	Tu	AD03,04,05	118.7	MC12	
34	6/17	We	AD06,07,08	136.9	MC12	
35	6/18	Tu	FDC01,AD09	128.9	MC12	
36	6/19	Tu	AD10,11,12	109.5	MC12	
37	6/20	Fr	AD13,14	82.3		14:30 Moving to Mc13
38	6/21	Sa	ctdLC01	190.1	MC13	03:30 Start
39	6/22	Mo	AD02,03,04,05	118.5	MC13	
40	6/23	Tu	AD06,07,08	124.8	MC13	
41	6/24	We	LC09,10	117.7	MC13	
42	6/25	Tu	FDC01,AD11	110.6	MC13	
43	6/26	Fr	AD12,13,14		MC13	15:50 Moving to MC02
44	6/27	Sa	ctd08	176.2		07:10 Start
45	6/28	Su	SSS03,04	47.6	MC02	
46	6/29	Mo	SSS03-1,FDC01	85.5	MC02	
47	6/30	Tu	FDC02,03,LC09	77.9	MC02	
48	7/1	We	AD10,11,12	87.3	MC02	
49	7/2	Tu	LC13,14,15	16.2	MC02	20:00 Finish
	7/17	Fr	Arrival in Guam			

Chapter 2 Survey Methods

In 1998, the fourth fiscal year of the Third Phase of the five year SOPAC Program, topographical survey and other surveys relevant to submarine mineral resources exploration were carried out, as planned, within the exclusive economic zones of the Republic of the Marshall Islands (27 day cruise from the 8th to 27th of May and from the 31st of May to 6th of June), and of the Federated States of Micronesia (22 day cruise from the 28th to 30th of May and from the 14th of June to 2nd of July). The target of the survey was cobalt-rich manganese crust deposits (henceforth cobalt-rich crust deposits).

Seamounts for study were selected from previous data, during the cruise the existence of these seamounts was first confirmed and then topographic, acoustic, seafloor observation, sampling and other surveys were carried out. On land; samples were identified and analyzed, data were analysed and interpreted, and the results were integrated into a report.

The following is a report of the survey in the exclusive economic waters of the Republic of the Marshall Islands.

The present work comprised mineral resources exploration in the waters of the Marshall Islands which was not surveyed during the cruise of Fiscal 1996 (ref. photo).

2-1 Selection of Seamounts

Near the Marshall Islands, concentration of cobalt-rich crusts is known to occur in the international waters on the northeastern side of the economic zone. Also the seamounts are concentrated in the northern part of the exclusive economic zone. Thus the survey was centered in the northern waters.

Also as the present work was to clarify the conditions of the unexplored waters, western part of the Marshall Islands was surveyed near the Anewetak Atoll.

In selecting the seamounts, for the survey, we first prepared seafloor topographic maps of the survey area by referring to the ETOP05 Topographic Grid Data prepared by NOAA (USA) and to the "Global Seafloor Topography from Satellite Altimetry and Ship Depth soundings (W.H.F. Smith and D.T. Sandwell, submitted to *Science*, April 7, 1997)". Seamounts were thus extracted and four seamounts were selected for survey referring to the results of the past surveys and also considering the cruise schedule.

The location of the seamounts were confirmed by referring to the "Global Seafloor Topography from Satellite Altimetry and Ship Depth Soundings"

2-2 Survey Methods

Survey of each seamount consisted mainly of the following work; topographic survey for clarifying the detailed seafloor topography, sampling by arm dredge (AD) or chain bag dredge (CB), and large corer (LC) for assessing the occurrence of the ores, and sea bottom observation by FDC for clarifying the continuity of the ore deposits and the conditions of the seafloor. Also SBP survey was carried out parallel with the topographic cruise for clarifying the conditions of the sediments and the structure of the shallow zones below the seafloor. And SSS survey was done in order to understand the micro-topography and the details of the seafloor sediments.

The duration of the survey for each seamount was decided to be six to seven days after considering the size of the seamount, the water depth of the summit, and the time necessary for sufficient accuracy.

2 - 3 Numbering

The numbering system used is as follows.

For sampling points: Year - S - Area No. - Method used - Sample No.

S denotes SOPAC, areas numbered sequentially from the previous survey for each country from MS10 to MS13, samples numbered sequentially regardless of the method used.

Examples: 98SMS10CB01 (CB survey)
9SMS10AD03 (AD survey)
98SMS10LC02 (LC survey)

For SSS survey: Year - Area No. - SSS - Sample No.

Samples numbered sequentially from 01 for each area.

Example: 98MS10SSSS01

For FDC survey: Year - Area No. - FDC - Sample No.

Example: 98MS10FDC01

2 - 4 Position Locating

The position of the survey ship was determined by GPS.

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

The water depths of the sampling points of dredges (AD, CB) and large corer (LC) were calculated on the basis of the TD sensor data attached to the tow line.

2 - 5 Acoustic Survey

The seafloor topographic survey was carried out by MBES and the main track line interval was basically 2.0 miles. Auxiliary lines were set between the main lines for shallow (under 2,000m) zones.

The ship speed was basically 10 knots with MBES sounding every 5~10 seconds and NBS sounding every 8 seconds.

SBP data were obtained parallel with the topographic survey for all seamounts.

One or two SSS survey lines were set for three seamounts. Tow speed was 2~3 knots, the vehicle was towed 100m above the seafloor and the data were obtained for a width of approximately 1km including both sides.

2 - 6 Seafloor Observation and Photography

Seafloor was observed by FDC equipment with TV and still cameras, and CTD. Real time color TV observation was done at about 1 knot tow speed and interesting and distinctive features were photographed by still cameras.

The observation lines were set mostly downward along the peripheries and the slopes (ridges, valleys) of seamounts navigating against the current and wind.

2 - 7 Sampling

CB, AD, and LC were used for sampling. The sampling sites were determined considering the water depth and the direction of the slope referring to topographic maps, MBES acoustic reflection intensity maps, and SBP data. Also the distribution of the sampling sites was designed to represent the geology and the cobalt-rich crust occurrence of the total seamount.

2 - 8 CTD Measurements

Vertical CTD measurement was carried out for each area before the topographic cruise in order to determine the sonic velocity necessary for MBES. This was done simultaneously with deep- zone LC sampling.

2 - 9 Processing and Analysis of Survey Data

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

The collected cobalt-rich crust samples were assayed, studied by EPMA and other methods in order to determine the grade, chemical composition, and texture. The rock and sediment samples were observed microscopically, chemically analyzed, and microfossils identified. Thus, geological information necessary for ore-deposit investigation was obtained.

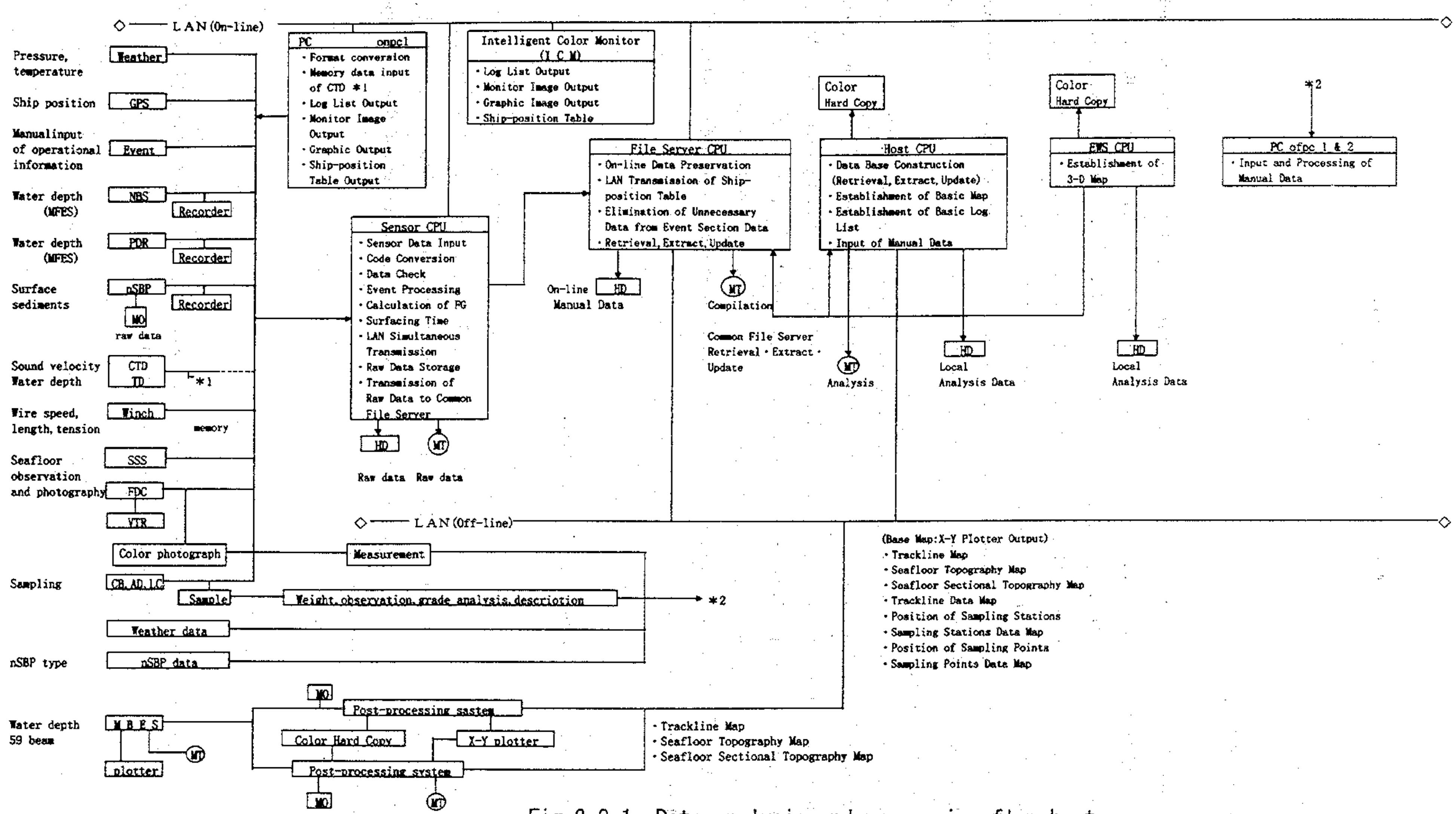


Fig. 2-9-1 Data analysis and processing flowsheet

Chapter 3 Results of the Survey

3 - 1 Topographic Survey

(1) Outline of topography

The Republic of the Marshall Islands is located in the northeastern part of the Central Pacific, and is surrounded by Central Pacific Basin to the east, and by Mariana and Nauru Basins to the west and southwest respectively. The islands are arranged in the NNW-SSE direction. In the southern extension of these islands, there are the Gilbert Islands and the Cook Islands further south. The Marcus-Wake Seamount Chains ranges to the north of the Marshall Islands. (ref. Figure 3-1-1)

The Central Pacific, Mariana, Nauru, and other basins constitute deep oceanic seafloor exceeding water depth of 5,500m, and thus the seamounts and atolls of this area have relative height of 3,500~4,000m and not a few of them exceed 5,000m.

The atolls and seamounts continue in the NNW-SSE direction in three to four belts. They are; from the east westward, Ratak Chain including the Majuro Atoll, Ralik Chain including the Kwajalein and Pikinni Atolls, the seamount chain including the Anewetak Atoll and extending northwestward to the Marcus-Wake Seamount Group, and the seamount chain extending to the Magellan Seamount Group.

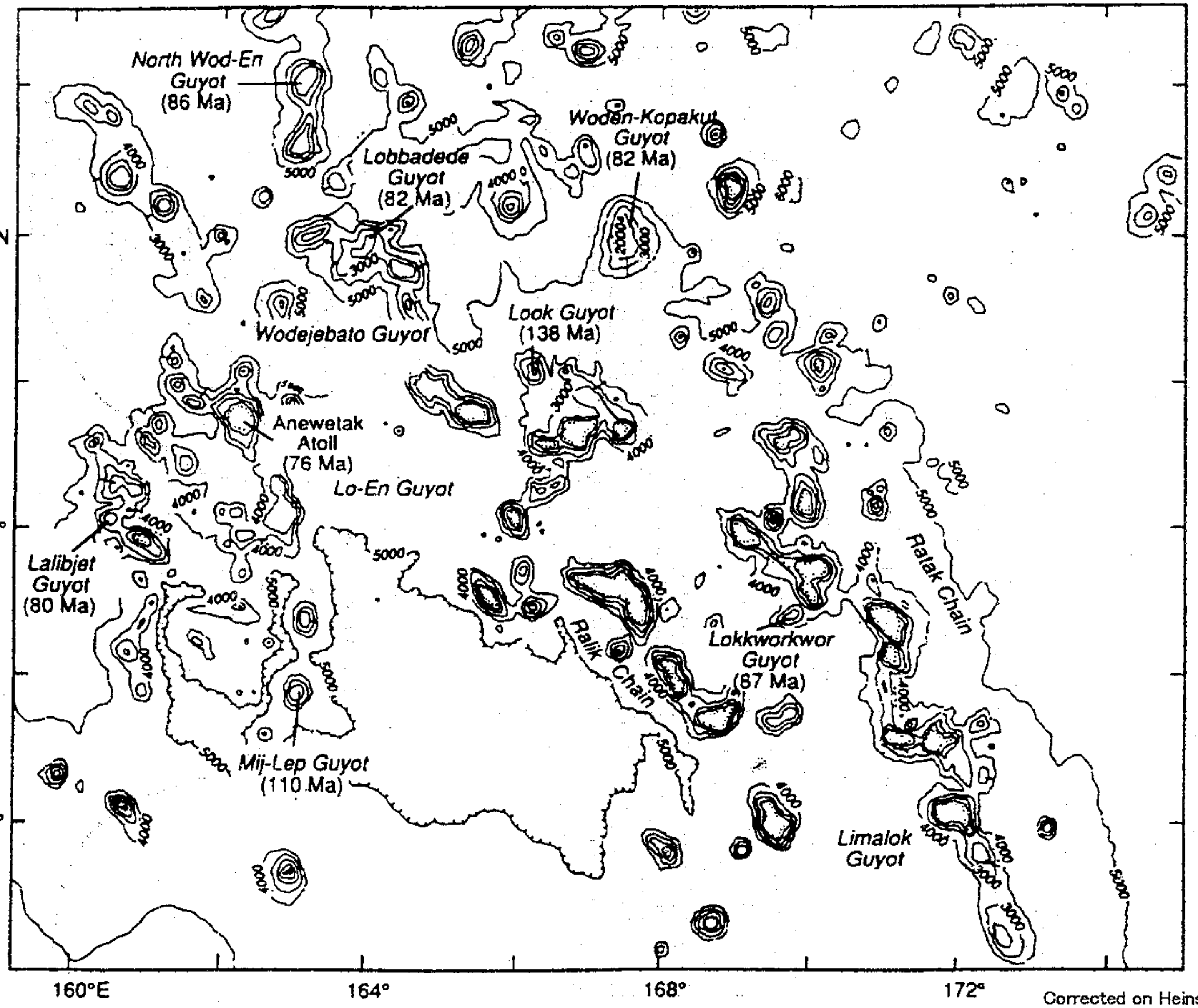
The four seamounts, namely MS10~MS13, surveyed during the present work are located near the Anewetak Atoll. MS01~MS03 and MS04~MS09 areas which were surveyed in 1996 belong to the Ralik and Ratak Chains respectively.

(2) Classification and topographic division of seamounts

These seamounts were classified as listed in Table 3-1-1. And the topography of these seamounts were divided into the summit and the slope as shown in Table 3-1-2 and Figure 3-1-2. The slopes of individual seamounts were further divided in accordance with topographic gradient. The water depth distribution of the summit and slope, however, differs by individual seamounts and thus topographic division by water depth has not been made.

(3) Results of topographic survey

The characteristics of individual seamounts are laid out in Table 3-1-3, and the statistics of gradient related with topographic division of individual seamounts are laid out in. Table 3-1-4.



Corrected on Heins, et al.(1990)

Fig. 3-1-1 Structural map around The Republic of The Marshal Islands

Table 3-1-1 Topographic Classification of Seamount

Classification	Characteristics of Shape
Table Seamount(guyot)	Seamount with summit comparatively flat and horizontal
Dome summit	Summit part has relative height with over 300m contour.
Flat summit	Summit part has relative height less than 300m contour.
Angular summit	Summit part is large but undulated.
Ridge-shaped Seamount	Seamount extended in one direction like a ridge
Plateau-shaped Seamount	A kind of table seamount whose summit is largely flat
Peaked Seamount	Seamount with little flat or horizontal part on summit

Table 3-1-2 Subdivision of Seamount

Classification		Topographical Characteristics
Summit	Central part	Central part of the summit with flat or gentle topography
	Marginal part or Periphery	Transitional 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 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

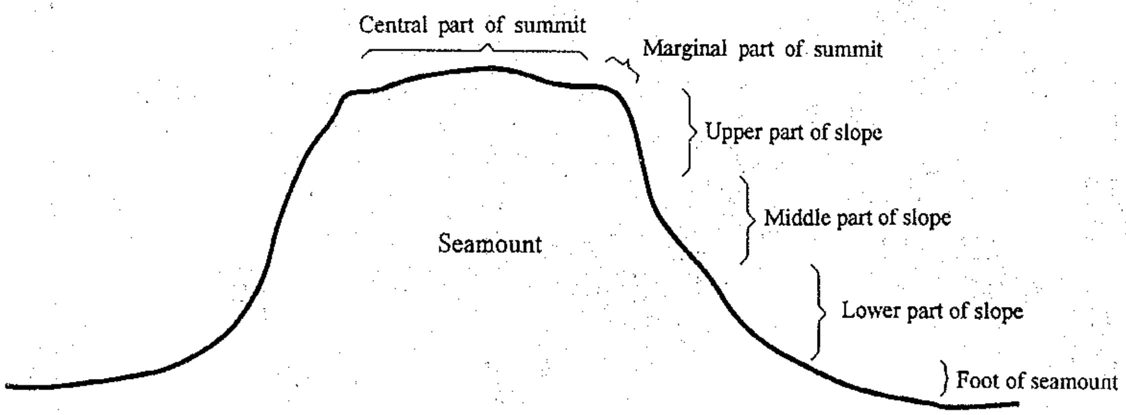


Fig.3-1-2 Schematic model of seamount subdivision

Table 3-1-3 Characteristics of Seamount

Area	Location	Type	Shallowest Depth (m)	Base Height (m)	Relative Height (m)	Seamount size (above 3,000m) long axis×short axis (km) long axis direction	Summit area (km^2)	Slope area (km^2) (above 3,000m)	Seamount characteristics
MS10	12°22′ N・158°38′ E	Guyot	1,292	5,600	4,300	22×20 NW−SE	134	455	Unconsolidated sediments over 50m thick on summit, NE slope is steep with few ridges.
MS11	10°55′ N・161°27′ E	Guyot	1,495	4,100	2,700	28×45 NNW−SSE	670	1,232	Relative height summit-shoulder is 700m. Unconsolidated sediment cover the above zone. Ridges extend in NE and SE parts, connects with other seamount in NW.
MS12	8°47′ N・163°12′ E	Guyot	1,037	4,900	3,860	40×30 WNW−ESE	235	929	Ridges extend in WNW and SW direction, the slope failure in between. Many small ridges in eastern side.
MS13	8°15′ N・160°40′ E	Rugged guyot	1,387	5,000	3,610	25×50 NNE−SSW	1,122	1,417	Rugged summit, few sediments except in northern part. Ridges extend in NE and NW direction, the former connects to a seamount in the north.

Table 3-1-4 Topographic Division and Gradient

Areas	Division	Water depth range (m)	Slope area (k㎡)	Average grandient (°)	Minimum gradient (°)	Maximum gradient (°)	Frequency distribution of gradient (%)			
							0-10	0-20	20-30	30 <
MS10	Summit	< 1,500	134	3.1	0.1	21.1	93.2	6.4	0.4	0.0
	Upper Slope	1,500 < 2,000	72	20.5	4.1	36.0	5.3	29.7	64.3	0.7
	Middle slope	2,000 < 3,000	249	17.9	0.3	36.0	7.6	58.2	32.8	1.4
	Lower slope	3,000 <	2392	8.9	0.0	49.2	63.3	31.6	5.0	0.0
MS11	Summit	< 2,100	670	4.5	0.0	32.6	90.3	8.6	1.0	0.0
	Upper Slope	2,100 < 2,500	206	14.4	0.1	39.9	37.5	36.9	20.8	4.8
	Middle slope	2,500 < 3,000	362	14.9	0.3	40.5	36.3	34.4	25.1	4.3
	Lower slope	3,000 <	1829	7.5	0.0	40.4	70.7	22.7	6.2	0.4
MS12	Summit	< 1,400	295	3.7	0.1	31.8	92.5	5.9	1.6	0.0
	Upper Slope	1,400 < 2,000	167	21.0	1.2	44.7	6.6	34.8	50.5	8.1
	Middle slope	2,000 < 3,000	467	17.9	0.4	50.5	10.9	53.4	32.0	3.7
	Lower slope	< 4,500	1565	10.5	0.1	44.2	57.5	31.7	10.0	0.8
MS13	Summit	< 2,700	1122	9.0	0.0	68.2	66.3	26.0	7.3	0.4
	Upper Slope	2,700 < 3,500	794	14.4	0.0	70.2	36.8	37.4	21.3	4.5
	Middle slope	3,500 < 4,000	747	11.0	0.1	71.3	53.8	31.0	14.0	1.1
	Lower slope	< 4,000	1067	8.2	0.0	33.4	67.6	27.0	5.2	0.2

The four seamounts surveyed are all guyots. Those in MS10~MS12 areas have gentle dome-like summit and the seafloor of the topographic section is very smooth. This is inferred to be caused by thick unconsolidated sediment cover and this is supported by subsequent MBES acoustic and SBP survey results. Outcrops are concentrated in the vicinity of the summit shoulders and the slope. And they are limited to near the pinnacles in the central parts of the summit.

On the other hand, many raised parts such as pinnacles are observed on the summit of the seamount in the MS13 area. Pinnacles extending parallel to the long axis are particularly notable, and the summit is generally uneven and full of relief. Thus the seamount in MS13 area is guyot, but is classified as rugged guyot. There are many outcrops on the summit and the unconsolidated sediments are inferred to thinly cover the depressions between the pinnacles.

Regarding the planar shape of the seamounts, that of MS10 seamount has relatively smooth surface and has concentric bathymetric contours. The seamounts in other areas show irregular bathymetric lines because of; developed valleys, terraces, and pinnacles on the slopes.

The three-dimensional images of these individual seamounts are shown in Figure 3-1-3 (1)~(4). Also seafloor topographic maps and topographic gradient maps are shown in appended Figures 2 (1)~(4) and 3(1)~(4) respectively.

The following is the characteristics of individual seamounts.

1) MS10 area

The seamount of this area is isolated guyot centered around 12° 20'N, 158° 38'E located to the northwest of the Eniwetok Atoll. The central part of the summit is flat gently rising toward the

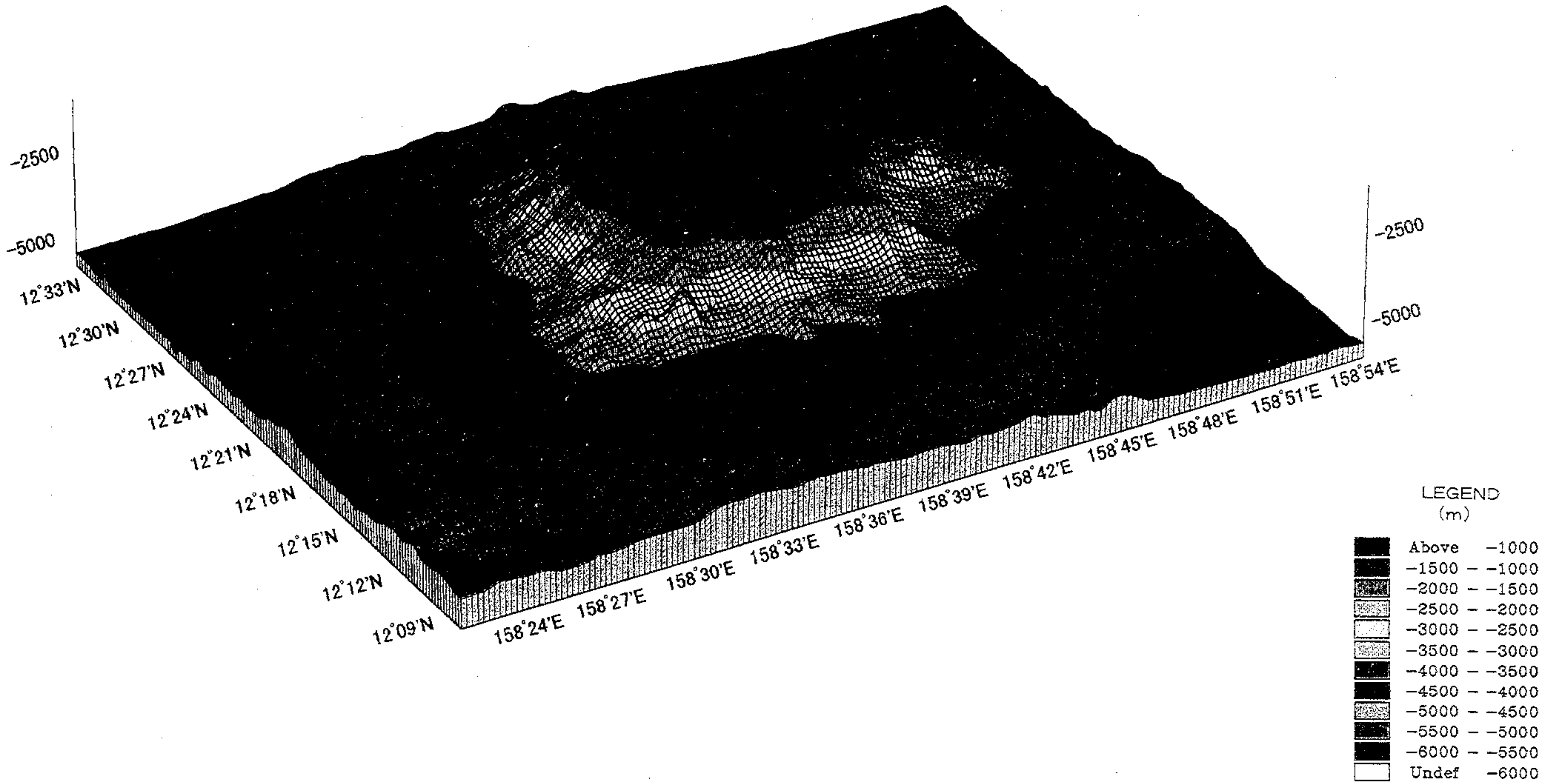


Fig.3-1-3(1) Bird's eye view of bathymetry of MS10 area.

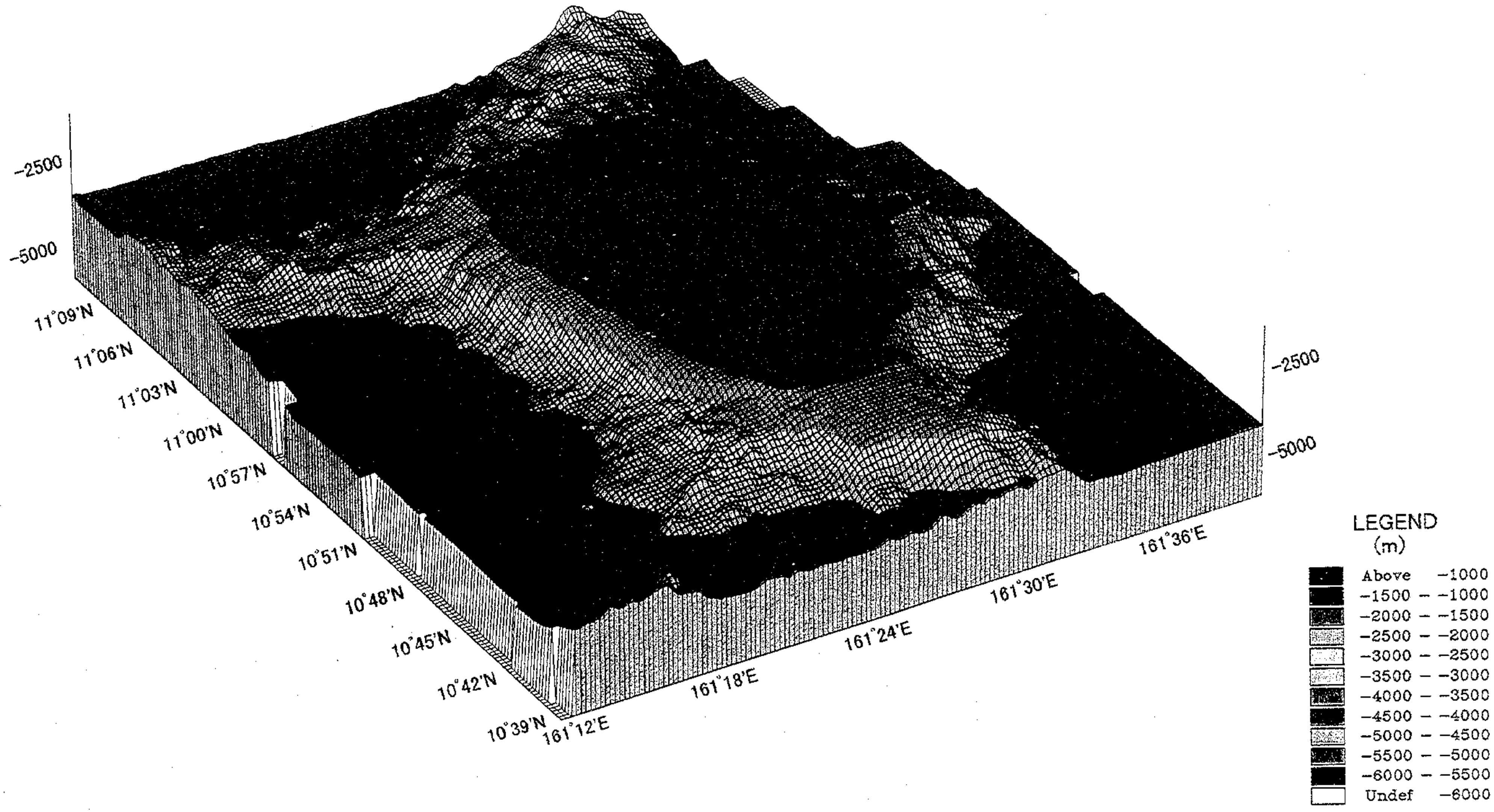


Fig.3-1-3(2) Bird's eye view of bathymetry of MS11 area.

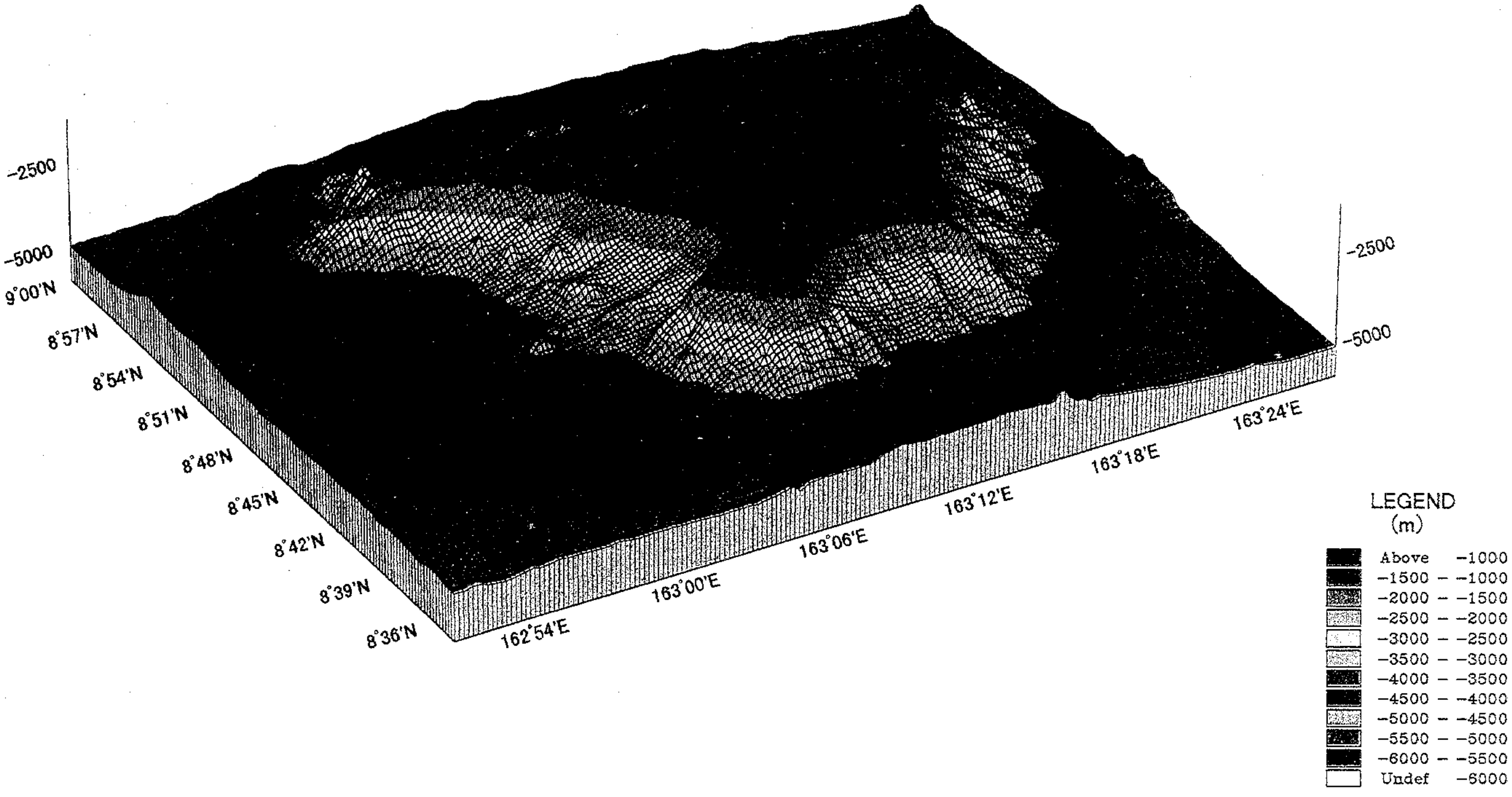


Fig.3-1-3(3) Bird's eye view of bathymetry of MS12 area.

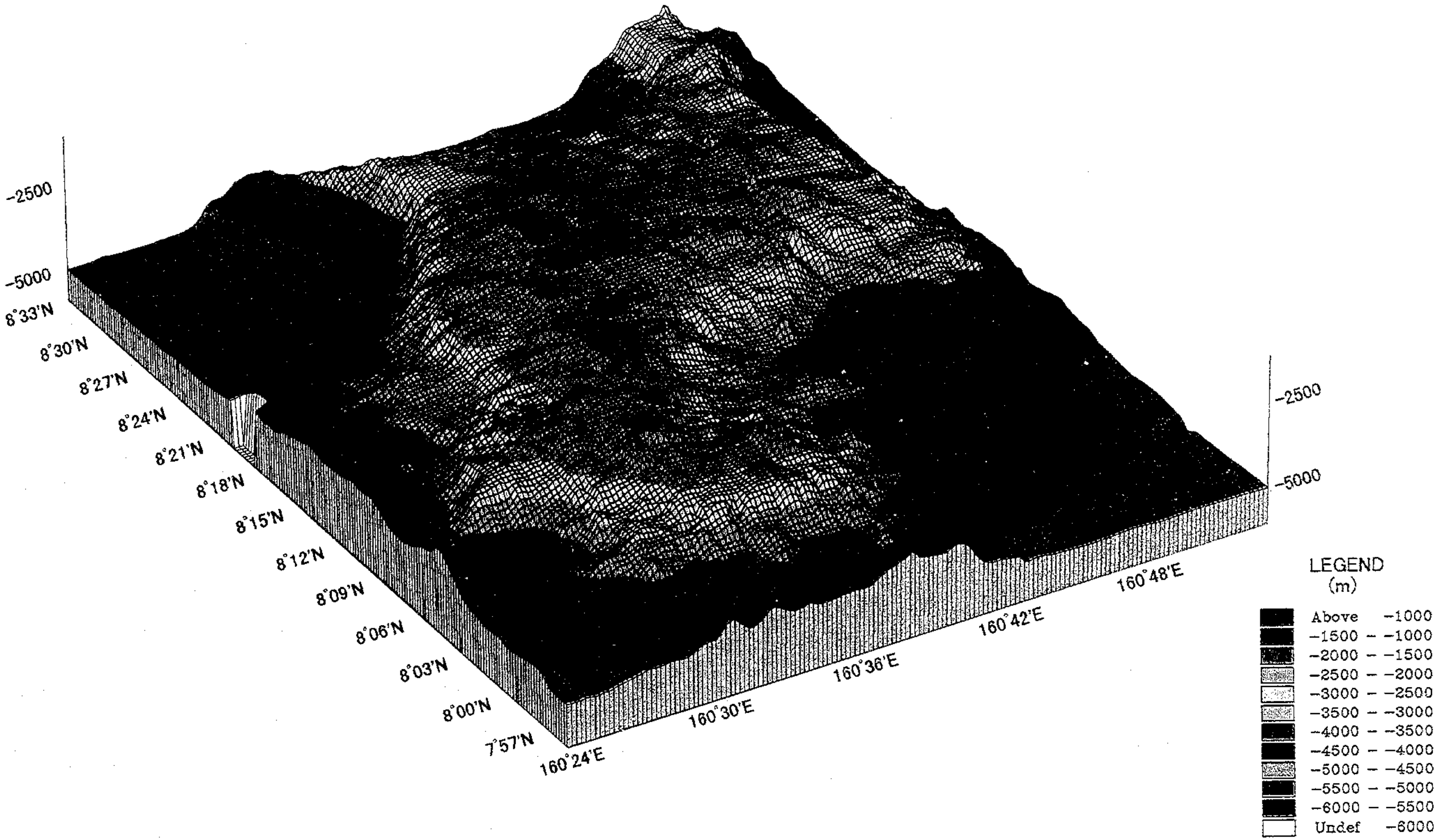


Fig.3-1-3(4) Bird's eye view of bathymetry of MS13 area.

center. The shallowest part is 1,292m deep from the sea surface and the relative height from the base is approximately 4,300m. The summit has oblong shape with 22km of long axis in the NW-SE direction and approximately 20km in the short axis. The long axis of the base is perpendicular to that of the summit.

The summit zone which is shallower than 1,500m water depth has an areal extent of 134° m^2 and the average slope of the summit is 3°. The summit is covered entirely by sediments with the exception of pinnacles. Thus it is very smooth with little relief.

The slope becomes gentler downward with average gradient of the upper slope 20.. 0°, middle slope 17.9°, and the lower slope 8.9°.

On the northern slope, notable ridges do not exist while many ridges are observed on the southwestern ~ northeastern slope. Small pinnacles occur sporadically on the ridges of the southwestern slope.

2) MS11 area

The seamount in this area is located approximately 60 miles east of the Anewetak Atoll and is on the same plateau. It is a guyot with a 700m high dome on the summit. The shallowest part is 1,495m deep from the sea surface, the summit has rectangular shape with long axis extending in the north-south direction, and is widely covered by unconsolidated sediments.

The water depth of the base is 3,800 ~ 4,000m, and the relative height of the summit is only around 2,700m. The size of the zone above 3,000m of water depth is 28 x 45km.

Terrace-like flat parts occur widely at 2,500m~3,000m water-depth zone on the northwestern and southeastern parts of the slope. The northeastern terrace is believed to be a topographic saddle extending to a seamount to the north of this guyot. This saddle has large relief with many pinnacles.

The western and northeastern slope is parallel to the long axis of the guyot in the NNW-SSE direction and is very linear.

3) MS12 area

The seamount in this area is an isolated guyot centered around 8° 50' N, 163° 12'. The water depth of the shallowest part of this guyot is 1,037m, and the relative height from the base is approximately 3,900m. The flat summit has an oval shape with long axis extending about 25km in the WNW-ESE direction and the short axis is about 15km. The base of the guyot is nearly circular. The summit above 1,400m water depth extends for 295km^2. The summit is widely covered by unconsolidated sediments with the exception of the pinnacles in the south. The unconsolidated material is 120m thick in the central part. Thus the seafloor at the summit is very smooth. The relative height from the periphery of the summit to the shallowest part is 300m forming a gentle dome structure. The inclination of the summit is less than 4°.

On the slope, ridges extend along the long axis and also in the direction perpendicular to this axis in the southwestern direction. The slope between these ridges form horseshoe-shaped valleys. Below 3,000m, the slope becomes gentle and forms a terrace.

The slope becomes gentler downward with the average gradient of the upper slope 21.0°, middle slope 17.9°, and the lower slope 10.5°. There are small ridges below the middle part in the northern to eastern slope with many small pinnacles.

4) MS13 area

The seamount in this area is located at 08° 15' N, 160° 40' E. Although this is classified as a guyot, the summit has notable relief with many pinnacles and rises. Thus this is classified as a rugged guyot. The shallowest part is near the center of the summit and the top of the pinnacle is 1,387m in water depth. The relative height from the base is approximately 3,600m.

The shape of the summit is rectangular with approximately 50km long axis in the NNE-SSW direction and 25km short axis. The width of the summit narrows and the topography becomes complex to the south. The summit above 2,700m water depth extends for 1,122km^2. The inclination of the summit is relatively steep for a guyot because of the pinnacles and other protrusions and the average is approximately 9°.

The average gradient of the slope is lower than other guyots by the effect of terrace topography at 14.4° in the upper part and 11.0° in the lower part. The slope to the north of 8° 20' N and the ridges extending in the northwestern and northeastern parts, however, are steep exceeding 30° as shown in the gradient map of Table 3-1-3.

There is another seamount 30 mi northeast of this guyot and it is inferred that the ridge extending northeastward connects to it.

3 - 2 MBES Acoustic Reflection Intensity Distribution Map

(1) Acoustic reflection intensity distribution of individual areas

The distribution of the MBES acoustic reflection intensity from the seafloor of each area is shown in Figure 3-2-1 (1)~(4).

The acoustic reflection intensity from the seafloor obtained by MBES reflect the conditions of the seafloor such as exposed rocks and unconsolidated sediments. The exposed rocks show high acoustic reflection intensity and is expressed in dark color (black) in the map, while unconsolidated sediments show low intensity and is expressed in pale color (white). When gravel and nodules occur on the unconsolidated material or when the unconsolidated sediments are coarse grained, the area is expressed in intermediate color (gray).

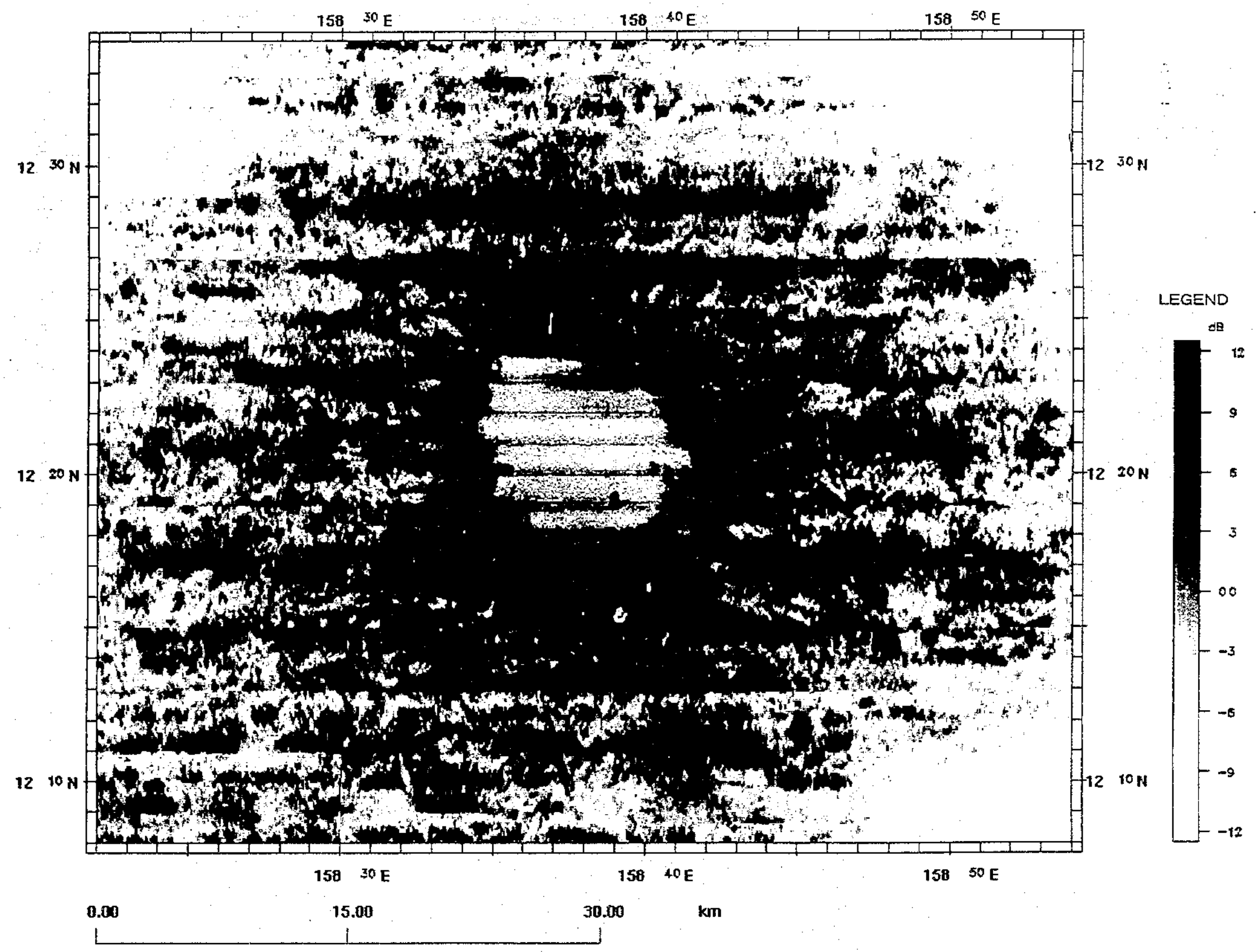


Fig.3-2-1 (1) Acoustic reflection intensity distribution of MS10 area.

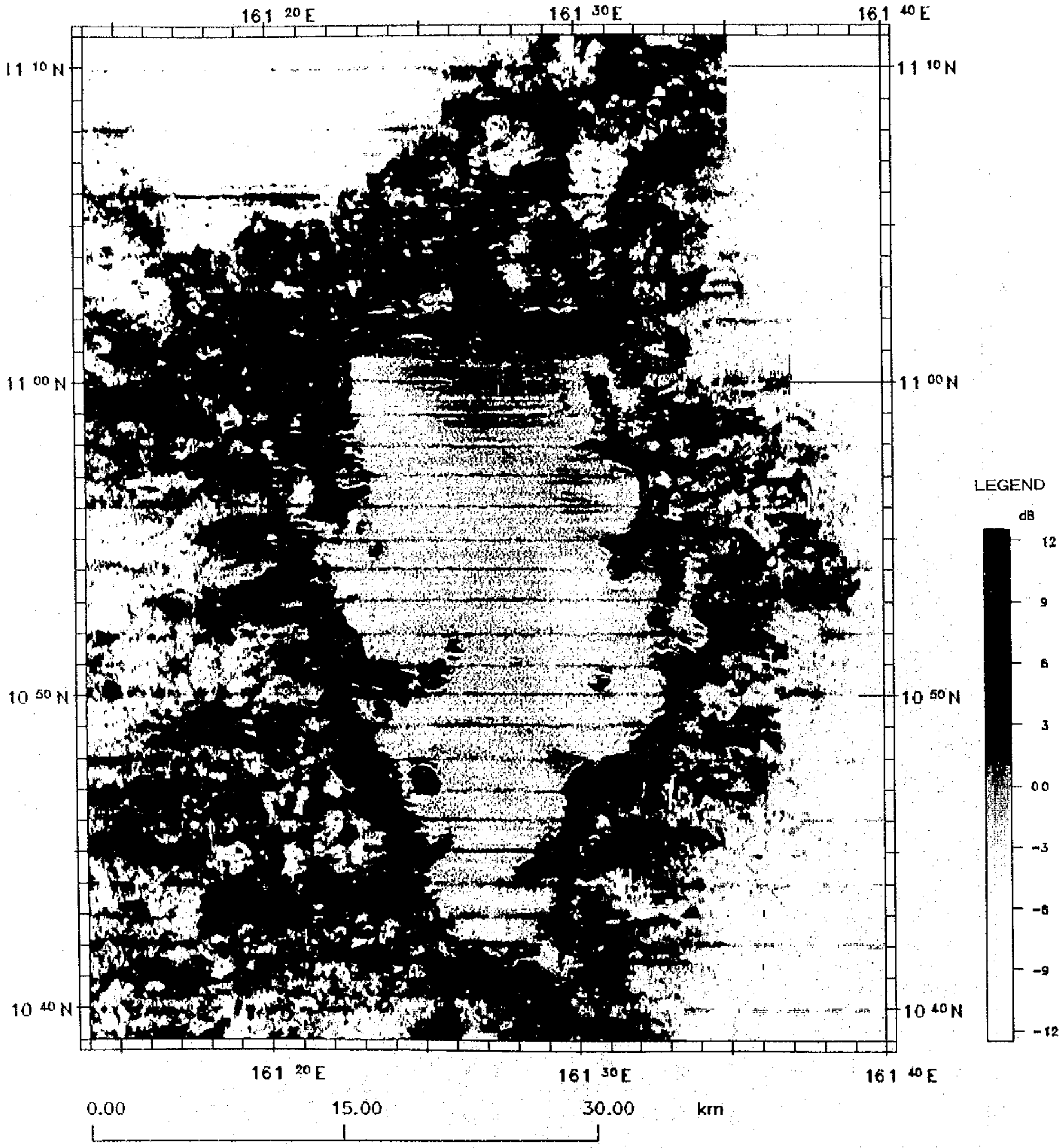


Fig.3-2-1(2) Acoustic reflection intensity distribution of MS11 area.

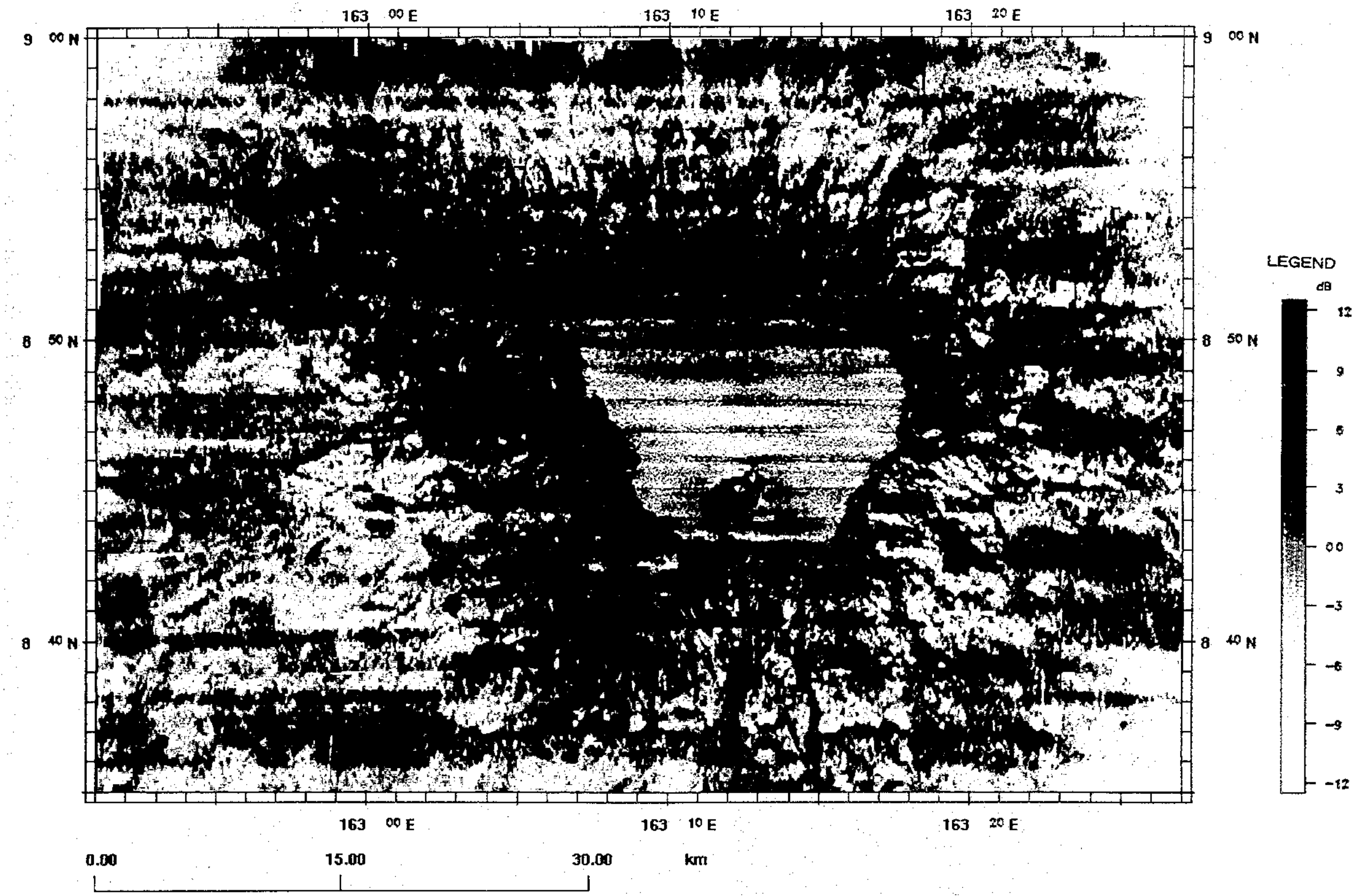


Fig.3-2-1(3) Acoustic reflection intensity distribution of MS12 area.

Fig.3-2-1(4) Acoustic reflection intensity distribution of MS13 area.

Of the four seamounts surveyed this year, three seamounts, MS10~MS12, are guyots with dome-shaped summit. The summit of these three guyots are generally covered by unconsolidated sediments. Thus the acoustic reflection intensity is low and pale-colored image extends over the entire summit. There are, however, some bedrock exposures such as pinnacles on these summits and these are expressed in dark-colored images. Particularly in MS11, pinnacles occur scattered along the periphery of the summit and these are correlated as high acoustic pressure parts (dark color) in the map.

The seamount in area MS13 which is classified as rugged guyot, has many pinnacles in the central part of the summit, and the unconsolidated sediment cover is thin. The acoustic reflection intensity map show complex pattern with alternating dark- and pale-colored parts indicating the exposures of the pinnacles and unconsolidated sediments in the depressions between the pinnacles.

The MBES reflection intensity patterns of the seamount slopes comprise both dark- and pale-colored zones corresponding to the ridges and valleys respectively. Also downward decrease of acoustic pressure is observed in the slopes of all seamounts. This indicates that the unconsolidated sediments become thicker and outcrops become fewer in the lower parts of the slopes.

The outline of the MBES acoustic reflection intensity distribution of each seamount is reported below.

1) MS10 area

Pale-colored parts with low acoustic reflection intensity corresponding to unconsolidated sediments are widely distributed in the central part of the summit of the guyot in this area. SBP record shows that these sediments thicken from the periphery towards the peak where it attains a thickness of 50m.

Notable dark parts of the image are the high acoustic pressure parts corresponding to pinnacles and bedrock exposures along the shoulder of the summit.

2) MS11 area

The peak of the guyot is approximately 700m higher than the peripheral shoulder of the dome-shaped summit. Pale-colored parts with low acoustic reflection intensity corresponding to the distribution of the unconsolidated sediments occur widely over the summit. Dark-colored parts with high acoustic pressure occur at the raised parts along the shoulder and at the basement exposure of the pinnacles. Also somewhat dark parts of the image indicating intermediate acoustic pressure occur in the northern part of the summit which is inferred to be caused by coarse-grained unconsolidated sediments or nodules.

Dark parts are distributed from the shoulders of the summit periphery to the upper part of the slope indicating high acoustic reflection intensity. Dark and pale parts occur on the slope corresponding to ridges and valleys, but generally the image become paler from the middle slope downward, indicating the thickening of the unconsolidated material. The topography of the northeastern and southeastern base is very flat and the acoustic reflection intensity is very low indicating the distribution of thick unconsolidated sediments.

3) MS12

Unconsolidated sediments occur widely in the central part of the seamount summit where the topography is a very gentle dome with little relief. The acoustic reflection intensity, however, is not constant and the level of acoustic pressure varies with the thickness of the unconsolidated sediments. Near the peak where the sediments are more than 120m thick, the image has pale color whereas it is dark where the sediments are thin such as the northern part of the summit and pinnacles. Highest acoustic pressure is observed at the shoulder near the periphery of the summit.

On the slope, the dark and pale parts alternates corresponding to the ridges and valleys, but the acoustic pressure weakens downward. In the eastern to the southeastern part, however, the image is pale even in the upper slope, and it is inferred that the whole slope is covered by unconsolidated sediments. Also pale image is observed on the terrace which extends in the western part at 3,000~4000m of water depth, indicating the existence of sediments.

4) MS13 area

The summit of this seamount has very complex topography with large relief consisting of many pinnacles and other protrusions. Thus the acoustic pressure is not even and the image shows complex distribution corresponding to the topographic relief. The topography is particularly complex in the summit south of 8° 20'N.

In the western margin of the summit, there are two rows of pinnacles extending parallel to the long axis and the corresponding high acoustic zones are striking. Dark parts indicating exposures are distributed all over the image with pale parts corresponding to unconsolidated sediments distributed locally between the pinnacles and in depressions.

Unconsolidated sediments are prevalent to the north of 8° 20'N and the seafloor is relatively smooth. SBP records show that the thickness of these sediments attain 100m in some places. Also low acoustic pressure zones indicating the presence of unconsolidated sediments occur on the wide terraces at 2,500~2,700m water depth in the northern to northeastern part, and at 3,500m water depth in the southeastern part. The image of the southeastern terrace has the most pale color tone and the sediments are considered to be particularly thick.