No. 13

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 FEDERATED STATES OF MICRONESIA

MARCH 1998

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

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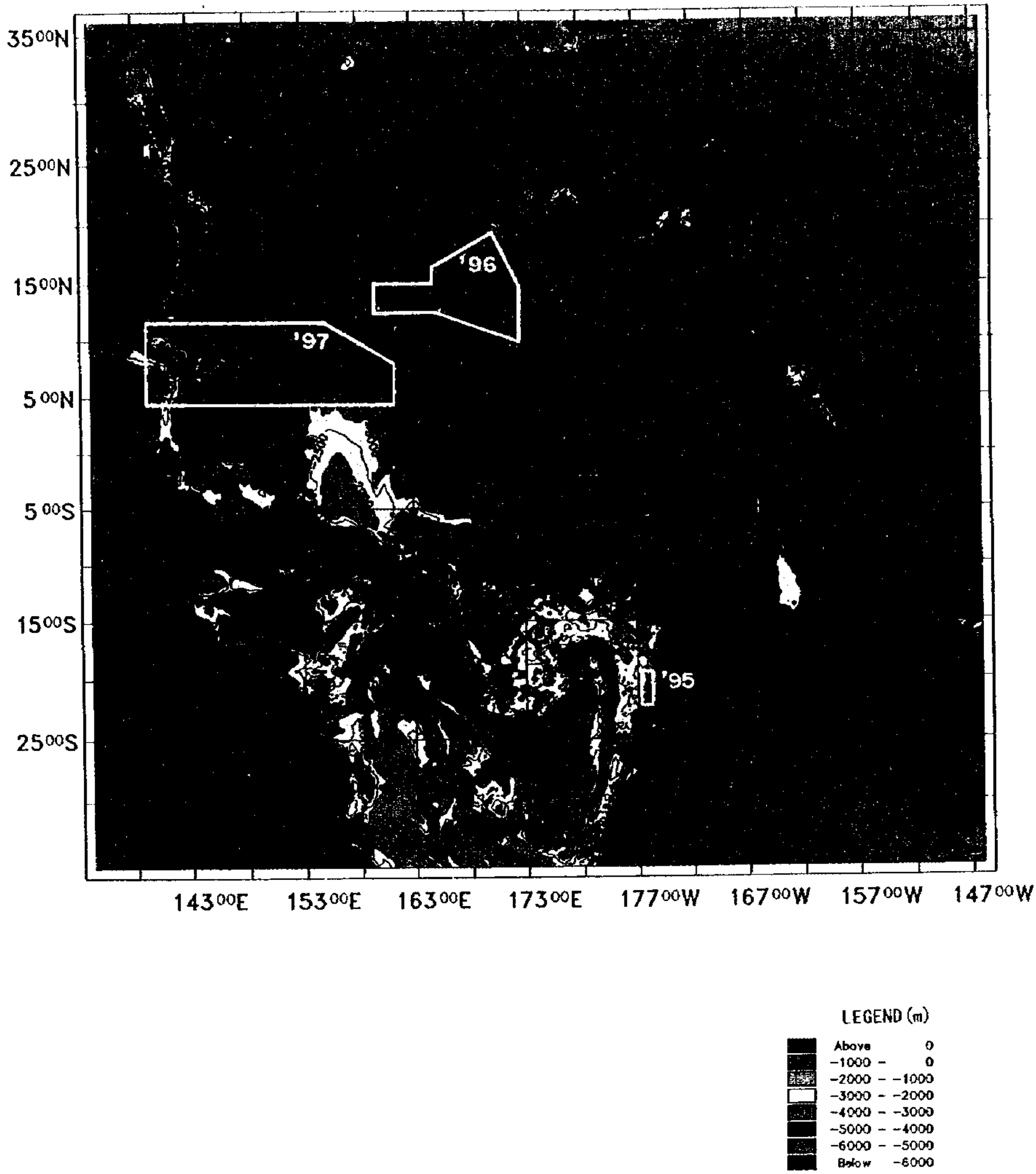
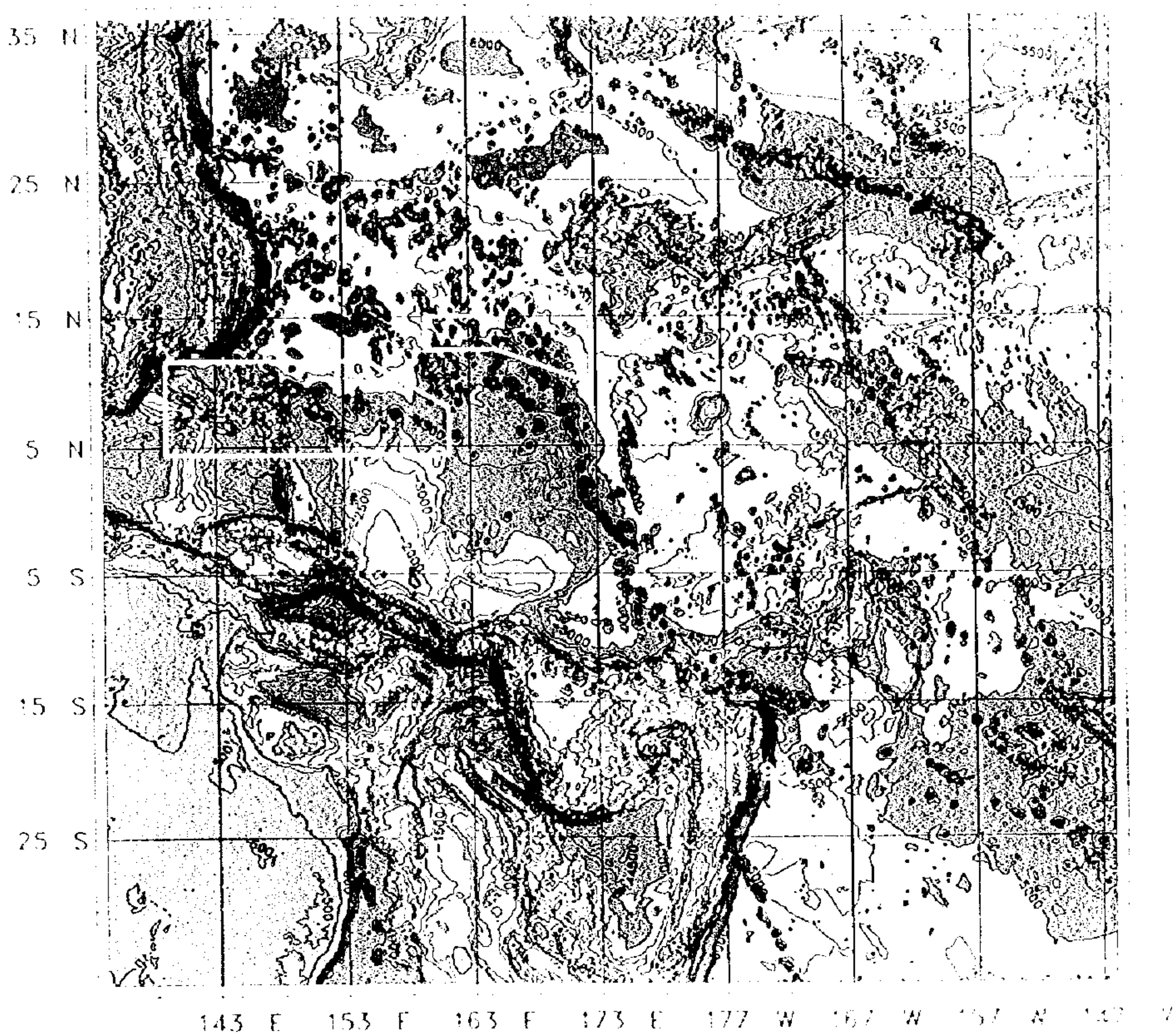


LOCATION MAP OF THE SURVEY AREA



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 resource 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 third year of the project, and the target area is the exclusive economic zone of 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 for a total of 74 days from July 15, 1997 to September 26, 1997, successfully completing the survey as planned with the cooperation of the Government of the Federated States of Micronesia.

The present report sums up the results of this third year survey.

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

March, 1998

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 third year. The survey for this year was carried out from July 15 to September 26, 1997 in an area of 1,900,000 km^2 in the exclusive economic zone of the Federated States of Micronesia. The duration of the survey was 74 days and the target mineral resources were cobalt-rich manganese crust deposits.

Oceanic islands, atolls, shoals, and seamounts occur scattered along two east-west trending oceanic ridges in the western side, namely the Yap Zone. On the eastern side, the Truk-Pohnpei Zone, oceanic islands and seamounts rising from the deep ocean bottom occur scattered, and the target seamounts belong to these groups. The seamounts were selected for survey considering the water depth of the summit (1,000~2,000 m were targeted because crusts are said to be best developed at this water depth), morphology, and size. ETOPO5 seafloor topographic data base of NOAA were used for this selection. Oceanic islands, shoals, and seamounts in six zones from the western side to the southern side of the survey area were selected for Leg 1, the first half of the survey, and those of four zones from the east to the northern side for Leg 2.

The survey consisted of; topographic cruise for clarifying the detailed topography of each seamount, seafloor observation by FDC and photography for confirming the continuity of the deposits, sampling by chain back dredge (CB), arm dredge (AD), and large corer (LC) was mainly carried out for determining the nature of the crusts such as type, thickness, grade, and coverage. Parts of the collected samples were studied on land by various types of analyses; X-ray diffractometry, microscopy, and other relevant methods, and the results were used for integrated analysis and interpretation together with the results of the onboard work. SBP survey was carried out parallel with MBES in order to clarify the distribution of unconsolidated sediments, and for some seamounts SSS survey was further made for the study of micro topography and nodule distribution.

Topographic survey was carried out in ten zones, and 13 seamounts were confirmed in nine zones by detailed topographic investigation. The shape of the summits of the seamounts are; six guyots (one oceanic plateau), one pointed, three oceanic ridges, two high relief type, and one shoal.

The acoustic image maps prepared on the basis of MBES acoustic reflection intensity were very effective in understanding the regional two-dimensional extent of exposed bedrock. These maps show that the bedrocks are exposed at summit pinnacles, the peripheral parts of summit, and steep slopes.

Also SSS survey provided very relevant data and information regarding the distribution of manganese crusts and micro topography by the availability of more detailed distribution of acoustic reflection intensity.

From seafloor observation by FDC, the mode of occurrence of cobalt-rich crusts of each seamount was confirmed. Particularly, the continuity of crust distribution, the type and shape of the crusts, distribution of unconsolidated sediments and talus, the relation of the above to micro topography were clarified. Also the linear distribution of the cobalt-rich crusts observed by FDC was used as the ground truth for interpreting the MBES acoustic reflection intensity images. It was confirmed by FDC observation that the cobalt-rich crusts of guyots occur covering the exposed rocks on pinnacles, summit peripheral parts, and slopes. It was also observed that in pointed, oceanic ridges, and high relief seamounts, limestone occur from the summit to the uppers slopes and basalt is distributed in the lower slopes, and it was confirmed that part of the above form talus.

Sampling was carried out at, on the average of, 15 sites for each seamount, and crust substrates, surface crusts, and bottom sediments consisting of foraminifera sand were recovered from all seamounts. Regarding the collected samples, type and thickness of cobalt-rich crusts were described onboard, and assay of crusts, fossil identification in limestone and foraminifera sand, chemical analysis and age determination of basalt were carried out on land.

Guyots including oceanic plateaus type seamounts, are distributed mainly in the northern part of the survey area, and they are harmonious with SBP transparent layers and low acoustic reflectivity. On the other hand, the oceanic ridge, pointed, and high relief type seamounts are distributed in the southwestern to eastern part and they are harmonious with SBP opaque layers and high acoustic reflectivity.

It was confirmed by sampling and seafloor observation that crusts with thickness exceeding 10 mm occur at water depth of 1,000 to 3,500 m. Cobalt-rich crusts occur as crusts, cobbles, and nodules and their thickness differs by area, topography, substrate, and other factors. Thus the mode of occurrence of cobalt-rich manganese crusts differ greatly by area. The guyots in MC02, MC08, and MC10 areas in the north, the average thickness of the crust is 20 mm, and crusts with more than 50 mm in thickness have been collected. While the seamounts in MC04, MC05, and other areas in the south, the crusts are well exposed, but they are very thin with an average of around 1 mm.

The relation between the occurrence of the crusts and the topography, geology ia summarized as follows.

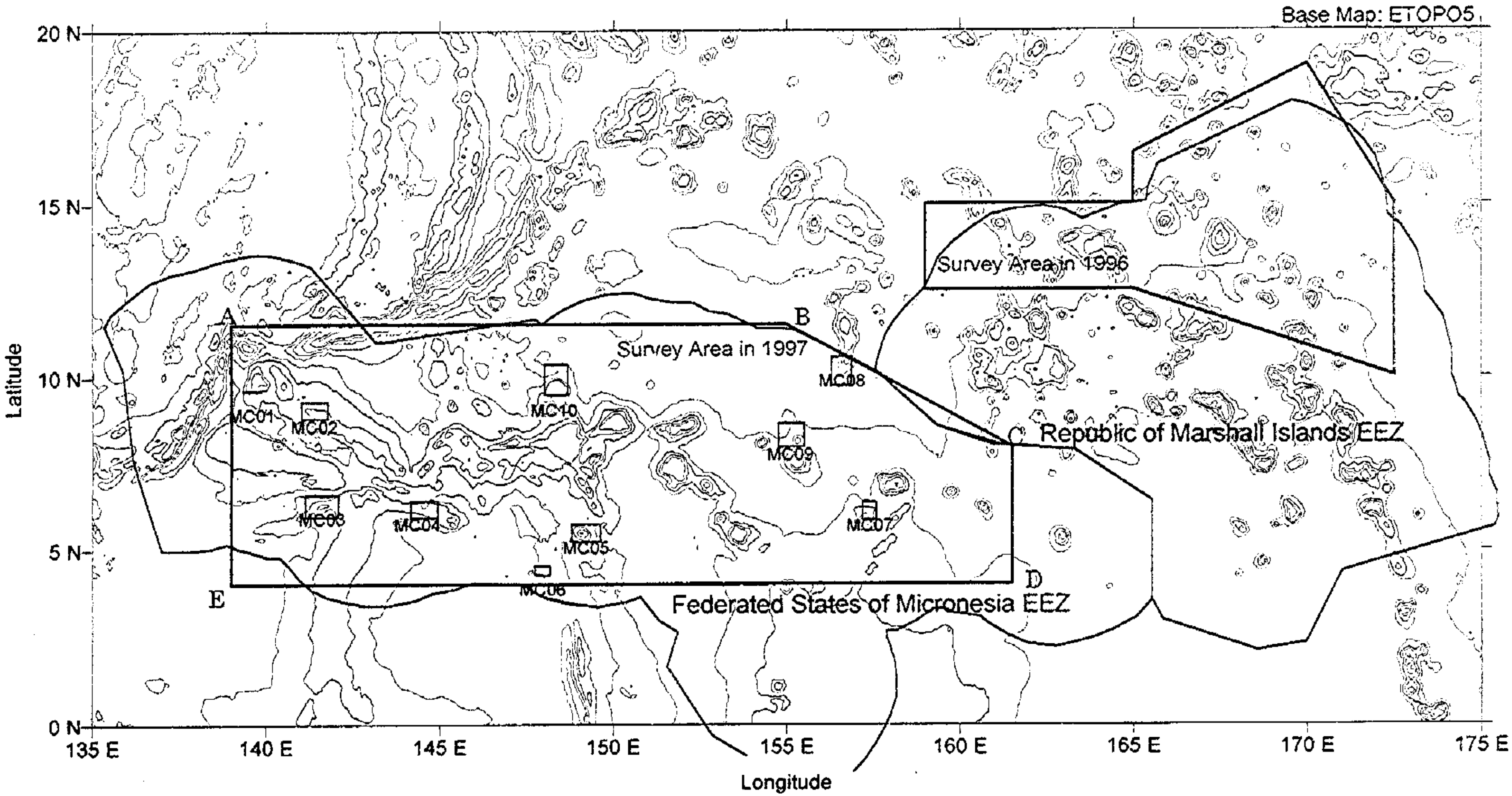
- The crust is well developed and thick on guyots older than Paleogene (MC08, MC10), and those on seamounts younger than Paleogene are thin.
- The thickness of the crusts on seamounts younger than Paleogene depends on topography and geology than the age.
- The seamount slopes shallower than 1,800 m of water depth are composed dominantly of reef limestone, and crusts on seamounts with these slopes (MC03~MC06) are thin.
- The crusts on pointed seamounts with very shallow summits (MC04, MC05) are very thin.

The average grade of the major elements also vary by area. In MC02, MC08, and MC10 areas, Cu content is higher and Co, Mn contents are lower than other areas, and the Co average grade is 0.33~0.36%

in the north while it is 0.38~0.48% in the south.

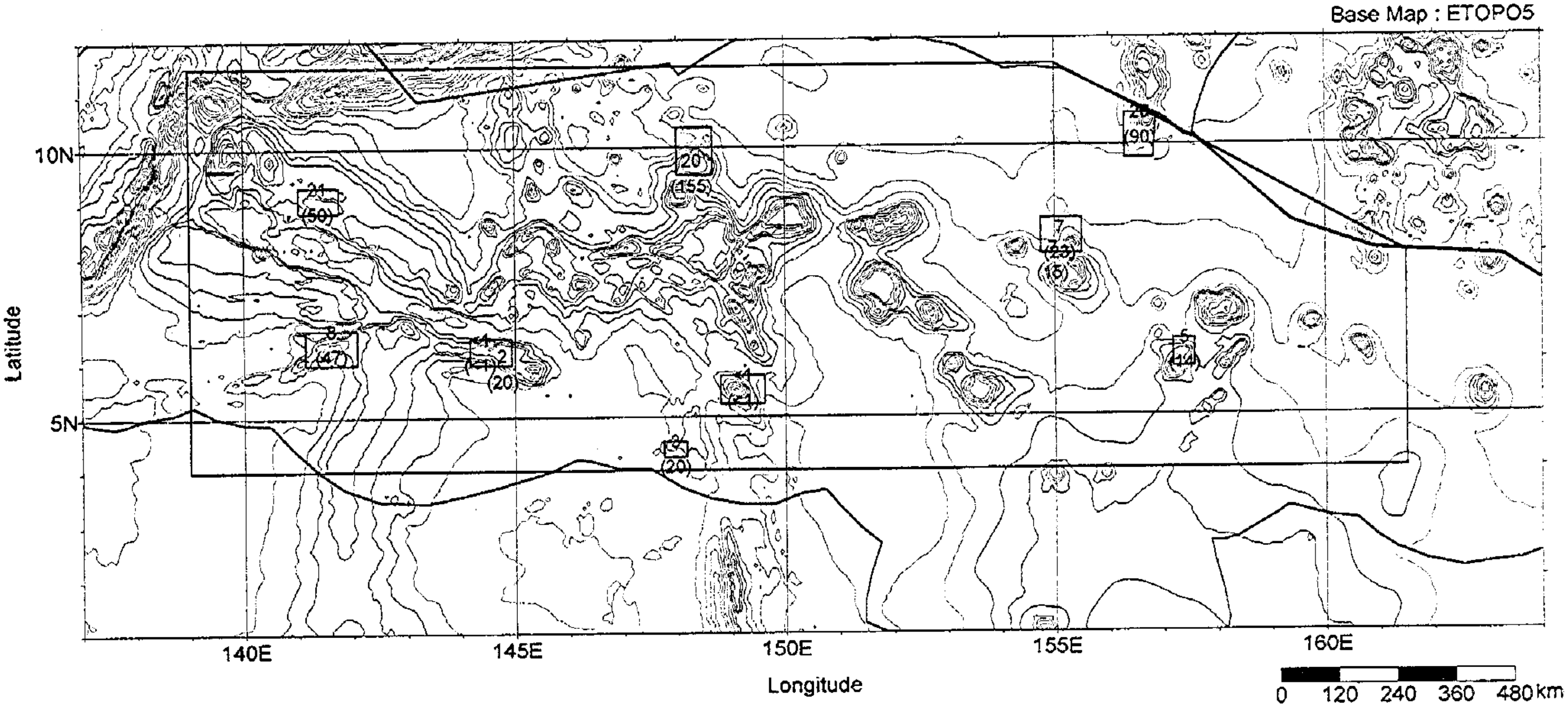
The resource potential of MC08 and MC10 areas in the north is assessed high on the basis of the manganese crust occurrences. From the above it is desirable to conduct further exploration in the north-northwestern part of the surveyed marine area where older guyots are believed to occur.

Large structures inferred to have formed by plate movements are observed in MC02 and MC03 areas. There is a graben structure deeper than 3,000 m of water depth to the north of both areas, and there are small depressions within this graben which can be considered to be the center of seafloor spreading. And since hydrothermal alteration is confirmed in some parts, the existence of hydrothermal sulfide deposits is expected. Although it is not clear whether the activity is continuing to the present and there is a possibility of being buried, it is a new target for further investigation.

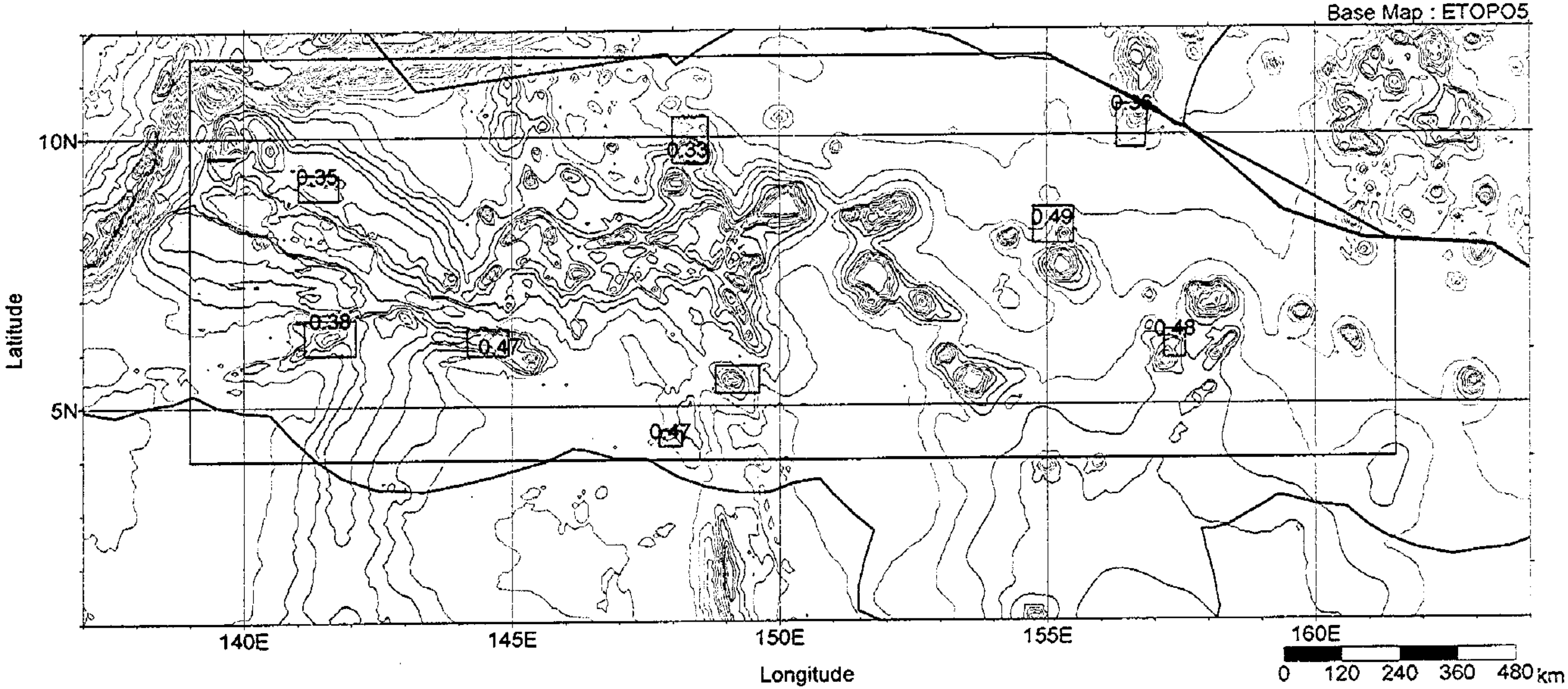


Location Map of the Survey Area.

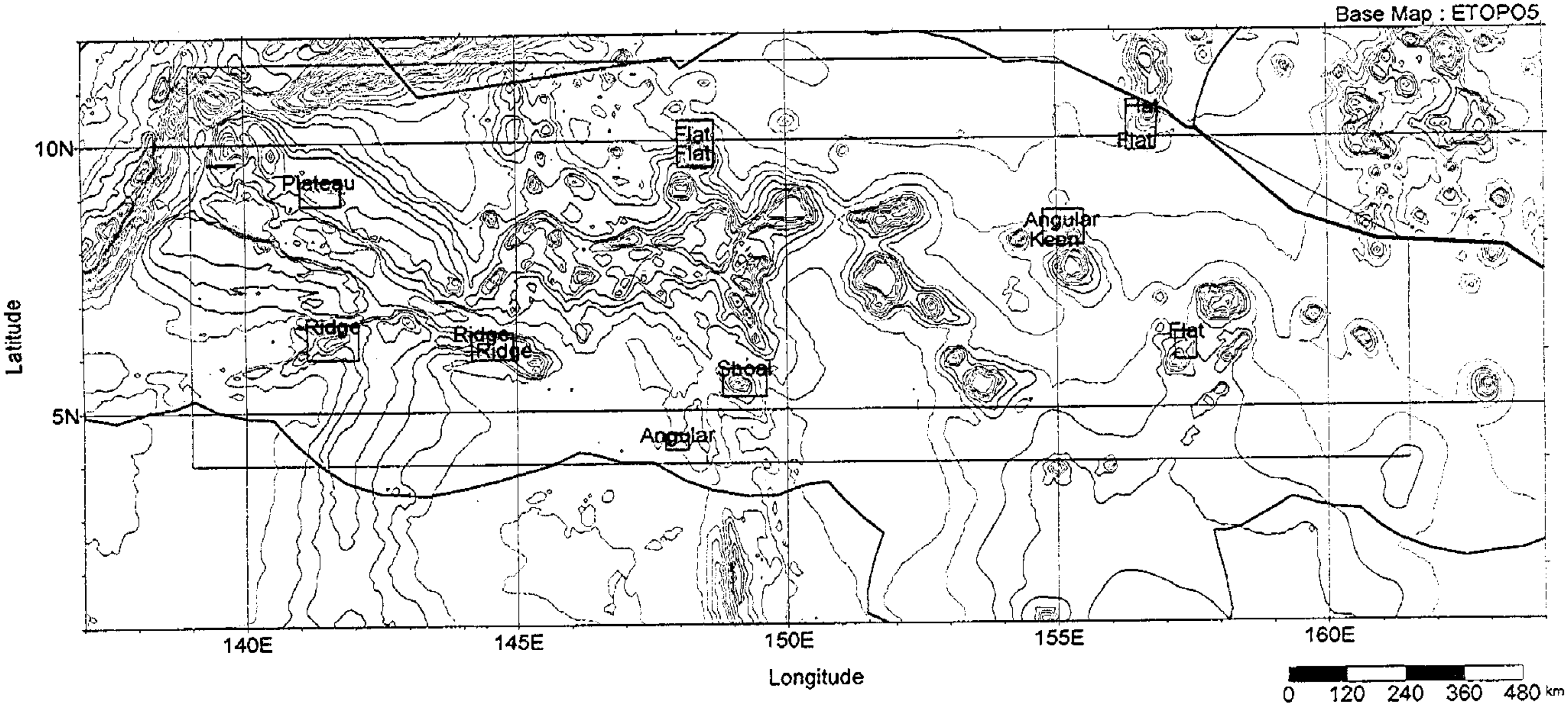
A 11-30'N 139-00'E
B 11-30'N 155-00'E
C 8-00'N 161-30'E
D 4-00'N 161-30'E
E 4-00'N 139-00'E
(Area: approx. 1,900,000km2)



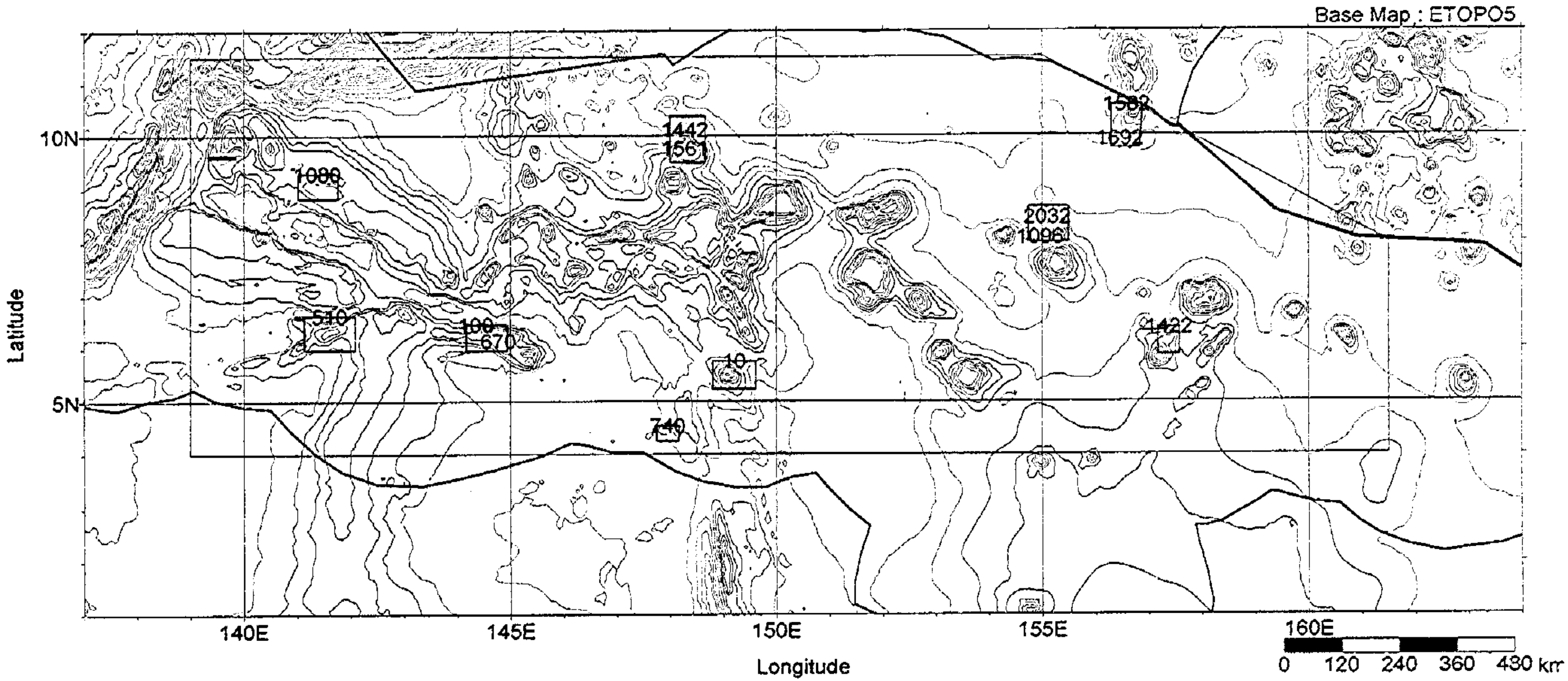
Thickness of Crust
Average
(max.)
Unit: mm



Average Co. Contents. (%)

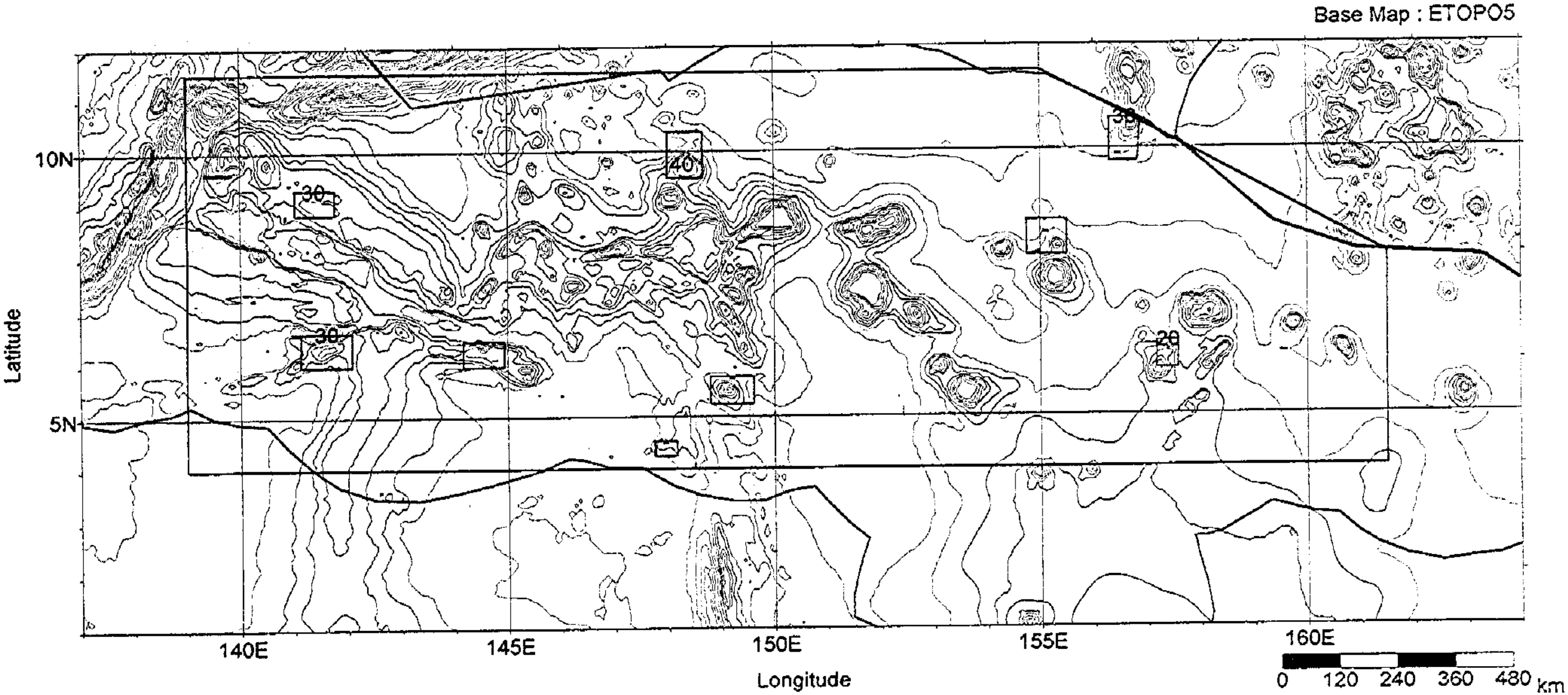


Shape of Summit.

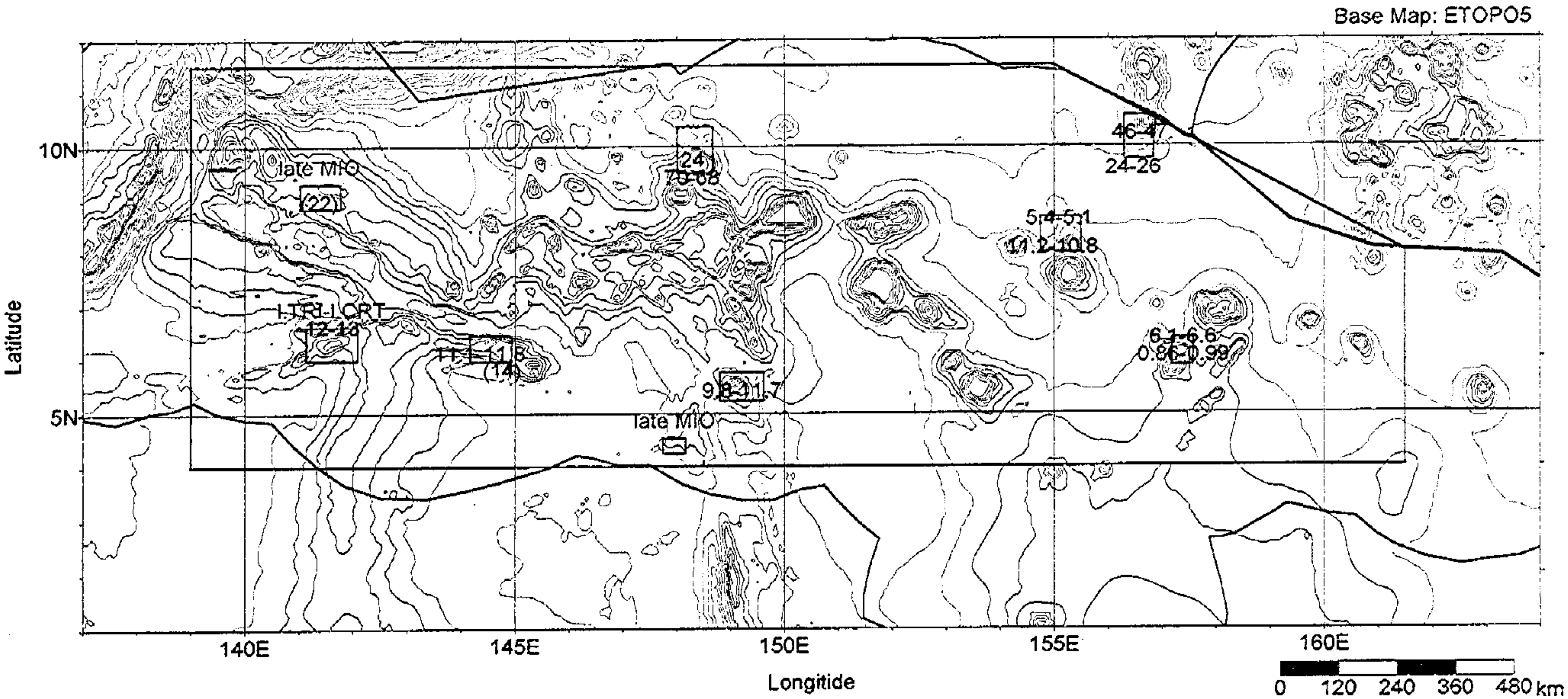


Shallowmost Depth of the Summit.

unit : m



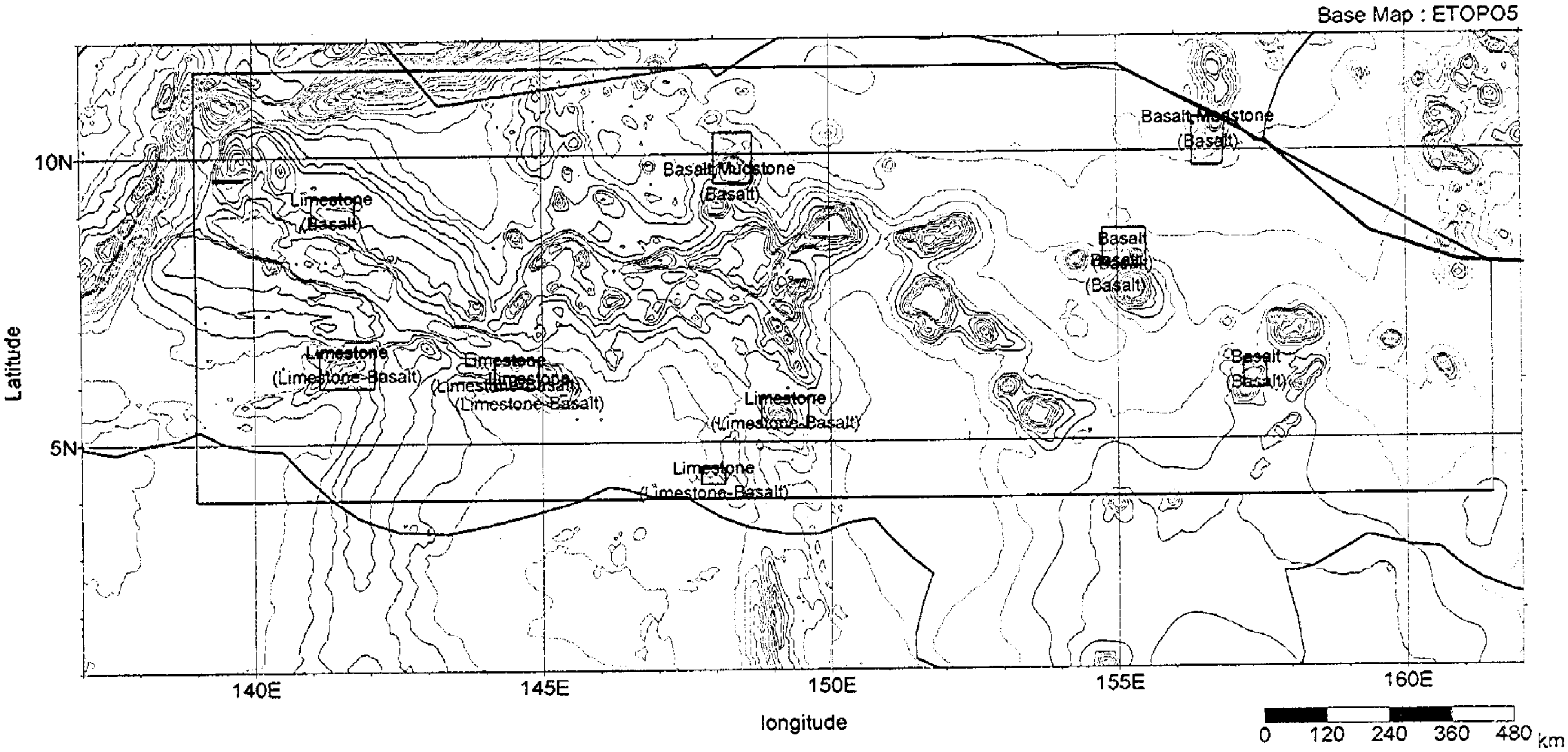
Thickness of Transparency Layer of Sub-bottom Profiling.
unit: m



Age of Sediments.

Age of Basalt (Summit zone) .
Unit : Ma

Age of Basait (Slope zone).
Unit : Ma



Geology

Summit
(Slope)

CONTENTS

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Chapter 1 Outline of the Survey

1–1 Survey Title

The Fiscal 1997 Joint Basic Study for the Development of Mineral Resources (Study for Marine Resources) in the Exclusive Economic Zone of the Federated States of Micronesia.

1–2 The Purpose of the Survey

The Purpose of the survey is to assess the potential of submarine mineral resources within the Exclusive Economic Zone of the Federated States of Micronesia, a member of SOPAC, through submarine topographical survey, sampling and other surveys.

1–3 Survey Area

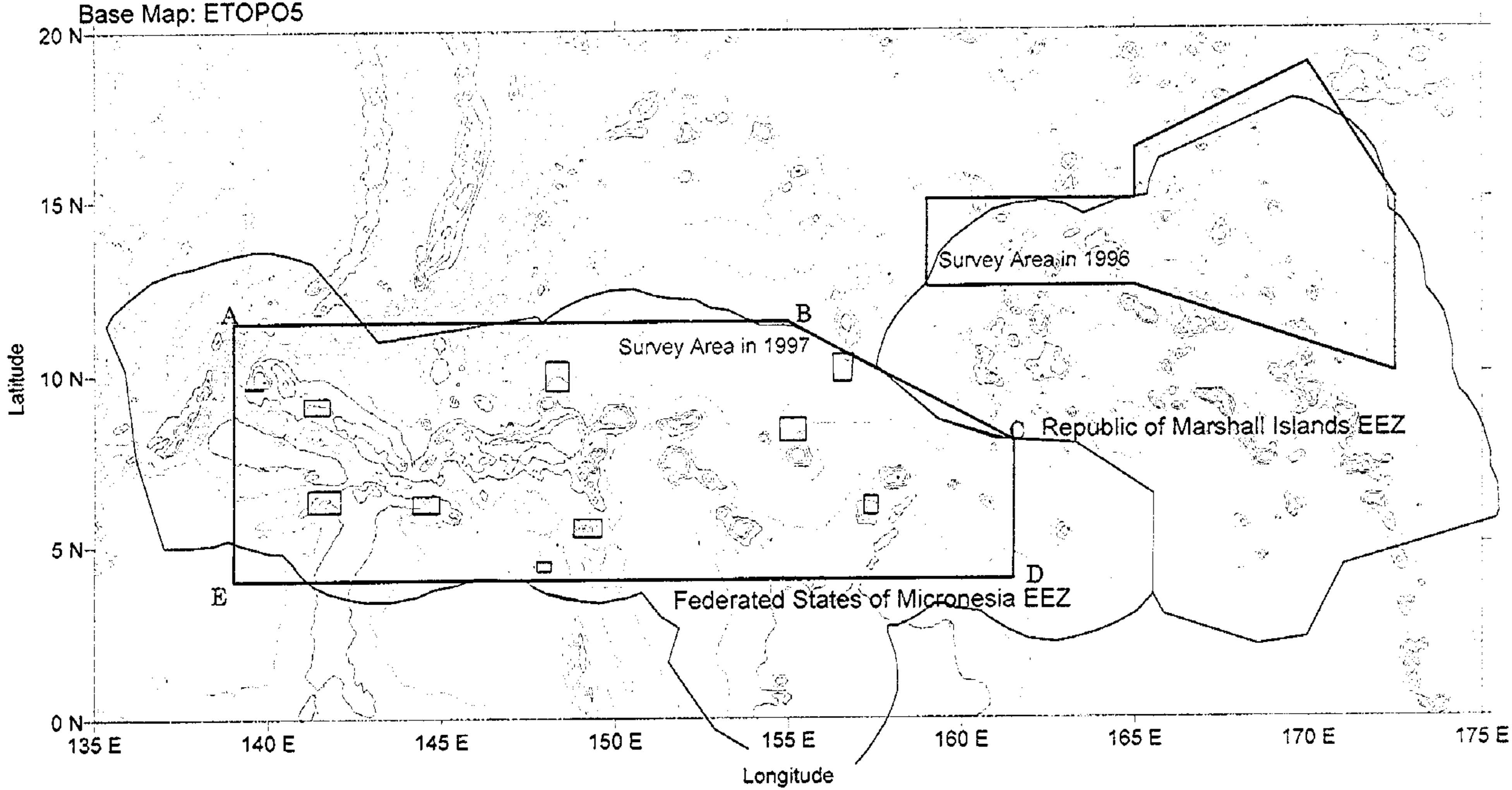
The survey area for this study is the area within the polygon obtained by joining the following coordinates (1,900,000 km^2, Figs. 1–3–1). This area was selected in accordance with the joint study program for marine mineral resources in the exclusive economic waters of the SOPAC member countries agreed upon by Japanese executing agency and South Pacific Applied Geoscience Commission (SOPAC) on 13 March 1995.

No	latitude	longitude
A.	11° 30'N.,	39° 00'E.
B.	11° 30'N.,	155° 00'E.
C.	8° 00'N.,	161° 30'E.
D.	4° 00'N.,	161° 30'E.
E.	4° 00'N.,	139° 00'E.
A.	11° 30'N.,	139° 00'E.

1–4 Duration of the Survey

Survey cruise: July 15 to September 26, 1997 (74 days)

Analysis and other work: April 1, 1997 to March 31, 1998



A 11-30'N 139-00'E
B 11-30'N 155-00'E
C 8-00'N 161-30'E
D 4-00'N 161-30'E
E 4-00'N 139-00'E
(Area: approx. 1,900,000km2)

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

1－5 Survey Participants

Japanese participants

Field supervisor:

Akira USUI (Geological Survey of Japan, August 25 to September 26, 1997)

Members:

Leader	Kohei MAEDA	(DORD) (7/25 ~ 9/26)
Maintenance	Nadao SAITO	(DORD)(8/25 ~ 9/26)
Geophysicist	Nobuyuki MURAYAMA	(DORD) (8/25 ~ 9/26)
Geologist	Takumi ONUMA	(DORD) (7/15 ~ 9/26)
	Kazunori MATSUI	(DORD) (7/15 ~ 9/26)
Geophysicist	Masahiro TAKEDA	(DORD) (7/15 ~ 9/26)
Geologist	Kenjiro KAWADA	(DORD) (7/15 ~ 8/24)
	Takayoshi KODAMA	(DORD) (8/25 ~ 9/26)
Deck	Hironori HISAMATSU	(DORD) (8/25 ~ 9/26)
	Seiji HASHIMOTO	(DORD) (7/15 ~ 8/24)
Geophysicist	Shuichiro YAMADA	(DORD) (7/15 ~ 8/24)
Deck	Kazuyoshi FURUYA	(DORD) (7/15 ~ 9/26)
Geophysicist	Michiharu ONO	(DORD) (8/25 ~ 9/26)
Photographer	Hitoshi MORIKAMI	(DORD) (8/25 ~ 9/26)
	Akio HAMANO	(DORD) (7/15 ~ 8/24)
Maintenance	Fujio TANAKA	(DORD) (7/15 ~ 8/24)
Geophysicist	Tadashi SATO	(O E D) (8/25 ~ 9/26)
	Satoshi OMI	(O E D) (7/15 ~ 8/24)
	Iori ONIZUKA	(O E D) (7/15 ~ 9/26)
	Yutaka HASHIMOTO	(O E D) (7/15 ~ 9/26)
	Kazuyoshi KUDO	(O E D) (8/25 ~ 9/26)
	Tsuyoshi SATO	(O E D) (7/15 ~ 9/26)

1–6 Survey Apparatus and Equipment

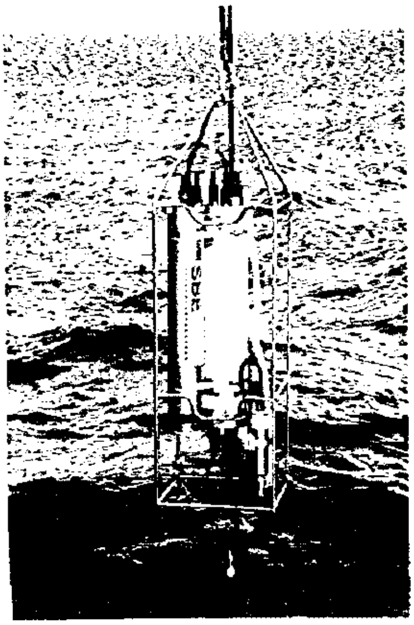
Major apparatus and equipment used during the survey are shown in Table 1–6–1 and Figure 1–6–1.

1–7 Survey Achievements

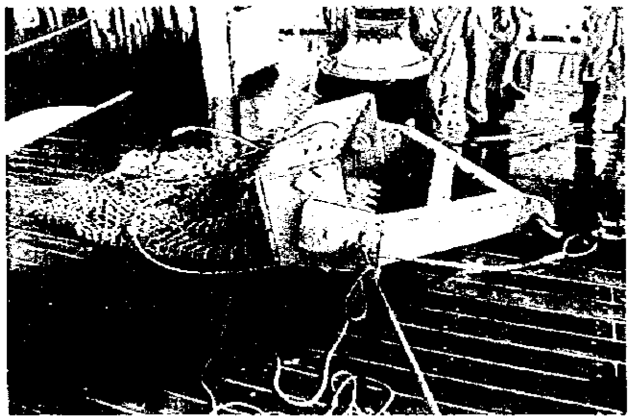
Survey operations were accomplished as shown in Tables 1–7–1 and 1–7–2 (1), (2).

Table 1-6-1 Survey apparatus and equipment

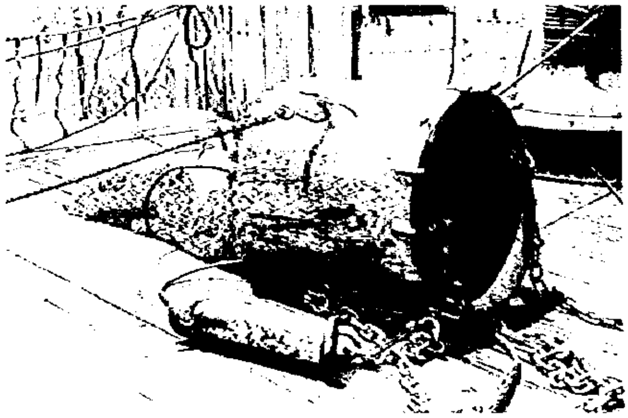
	Survey Method	Survey Apparatus and System	Abbre-viation	Remarks
Positioning	Satellite navigation	Global Positioning System	GPS	
Sea Bottom Topography and Geological Survey	Acoustic Sounding Bathymetry	Multi-narrow Beam Echo Sounder	MBES	
		Narrow Beam Echo Sounder	NBS	
	Subsurface Geological Structure	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	DPS	
	Data Storage Functions	Sensor CPU・File Server CPU		
	Off-Line Functions	Host CPU		
	↓	Engineering Work Station (EWS)		
	Track Line Maps			
	Various Plan Maps	Local Areal Network (LAN)		
	Cross Sections	Personal Computer (PC)		
	Data Analysis	Intelligent Color Monitor (ICM)		



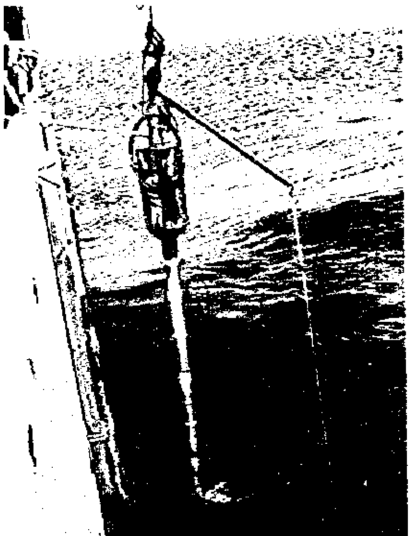
Conductivity,Temperature and Depth
Measurement System



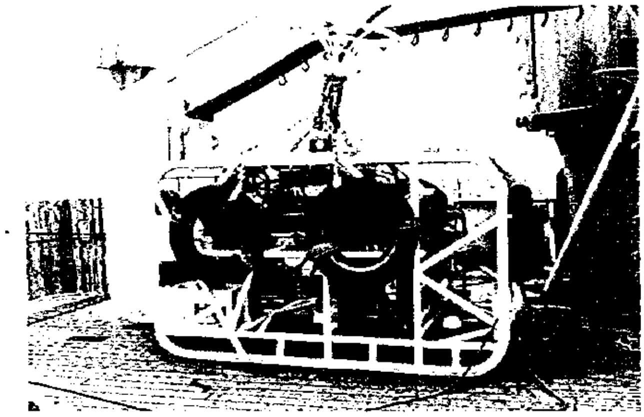
Arm Dredge



Chain-back Dredge



Large Gravity Corer



Deep Sea Towed Camera

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

Table 1-7-1 Survey achievements

Survey Schedule											
	Departur from Guam		7/17				Start of Leg1 survey		7月18日		
	Arrival at Pohnpei		8/20				Finish of Leg1 survey		8月19日		
	Departur from Pohnpei		8/23				Start of Leg2 survey		8月24日		
	Arrive Guam		9/26				Finish of Leg2 survey		9月23日		
	Total days of the voyage		72days				Total days of the survey		62days		
Survey district	10districts	MC01	MC02	MC03	MC04	MC05	MC06	MC07	MC08	MC09	MC10
Number of sampling sites	128	—	7	16	21	9	8	15	19	13	20
Kind of sampler CB	95	—	2	8	18	8	8	6	16	12	17
AD	9	—	1	4	0	0	0	4	0	0	0
LC	24	—	4	4	3	1	0	5	3	1	3
Amount of samples (kg)	2401.6	—	179.7	406.3	323.9	113.8	282.8	69.8	581.5	228.9	215.0
Crusts	328.3	—	12.3	31.5	3.1	0.0	18.6	10.0	137.2	68.5	47.2
Cobble crusts	937.7	—	0.0	258.8	97.7	0.0	122.0	6.0	279.8	99.1	74.3
Nodules	236.2	—	0.0	38.5	19.9	0.0	16.2	11.7	96.4	0.8	52.7
Thin coatings	268.7	—	0.0	0.0	88.7	56.0	54.6	0.9	5.5	44.3	18.6
Rocks	318.4	—	123.0	19.1	51.6	5.9	64.5	5.6	45.7	2.5	0.6
Sediments	312.3	—	44.4	58.4	62.9	51.9	7.0	35.6	16.9	13.7	21.6
Seafloor observation											
FDC Number of track lines	7	—	—	1	2	—	—	1	1	1	1
Length of track lines	32.4	—	—	5.7	8.8	—	—	6.3	4.5	2.3	4.8
Number of photos	1446	—	—	251	407	—	—	265	222	125	176
Number of video tapes	22	—	—	4	5	—	—	4	4	2	3
Acoustic survey											
Length of track lines MBES･NBS	6283	59.2	529.6	831.4	914.9	613.4	252.5	529.5	649.1	861.2	1042.2
Length of track lines SSS	18.6		10	4					4.6		

Table 1-7-2(1) Records of survey schedule (Leg. 1)

			Month/Day		Area	Survey Item		Remark
1			7/15	Tu				
2			7/16	We				
3			7/17	Th		* Departure from Guam		Moving to MC01
4			7/18	Fr	MC01		21:22 Bathymetric Survey	Moving to MC02
5	1	1	7/19	Sa	MC02	Sampling ctd-LC01	Bathymetric Survey	
6	2	2	7/20	Su			〃	
7	3	3	7/21	Mo		Sampling AD02,CB03	〃	
8	4	4	7/22	Tu		Sampling CB04,LC05,06,07	〃	
9	5	5	7/23	We		SSS Survey 01,02	〃	
10	6		7/24	Th			Bathymetric Survey	Moving to MC03
11	7	1	7/25	Fr	MC03	Sampling ctd-LC01	〃	
12	8	2	7/26	Sa		Sampling AD2,3,4,5	〃	
13	9	3	7/27	Su		Sampling CB6,7,8	〃	
14	10	4	7/28	Mo		SSS Survey 01	〃	
15	11	5	7/29	Tu		FDC Survey 01、01-1	〃	
16	12	6	7/30	We		Sampling CB9,10,11,12	〃	
17	13	7	7/31	Th		Sampling CB13,LC14,15,16	〃	
18	14		8/1	Fr			〃	Moving to MC04
19	15	1	8/2	Sa	MC04	Sampling ctd-LC01	Bathymetric Survey	
20	16	2	8/3	Su		Sampling CB02,03,04,05	〃	
21	17	3	8/4	Mo		Sampling CB06,07,08,09	〃	
22	18	4	8/5	Tu		FDC Survey 01	〃	
23	19	5	8/6	We		FDC Survey 02	〃	
24	20	6	8/7	Th		Sampling CB10,11,12,13	〃	
25	21	7	8/8	Fr		Sampling CB14,15,16,17	〃	
26	22	8	8/9	Sa		Sampling CB18,19、LC20,21	〃	
27	23		8/10	Su	MC05		Bathymetric Survey	Moving to MC05
28	24	1	8/11	Mo		Sampling ctd-LC01	〃	
29	25	2	8/12	Tu			〃	
30	26	3	8/13	We		Sampling CB02,03,04,05	〃	
31	27	4	8/14	Th		Sampling CB06,07,08,09	〃	
32	28		8/15	Fr	MC06		Bathymetric Survey	Moving to MC06
33	29	1	8/16	Sa		Sampling CB01,02,03,04	〃	
34	30	2	8/17	Su		Sampling CB05,06,07,08	〃	
35			8/18	Mo		* Departure from the survey area		Sailing to Pohnpei
36			8/19	Tu				Sailing to Pohnpei
37			8/20	We		* Arrival in Pohnpei		
38			8/21	Th				

Table 1-7-2(2) Records of survey schedule (Leg. 2)

			Month/Day		Area	Survey Item		Remark
39			8/22	Fr				
40			**8/23**	**Sa**		* Departure from Pohnpei		Moving to MC07
41	31	1	**8/24**	**Su**	MC07	Sampling,ctd-LC01		
42	32	2	8/25	Mo		Sampling CB02,03,04,05	Bathymetric Survey	
43	33	3	8/26	Tu		Sampling AD06,07,08,09	〃	
44	34	4	8/27	We		Sampling LC10,11,12,13	〃	
45	35	5	8/28	Th		FDC Survey	〃	
46	36	6	8/29	Fr		Sampling CB14,15	〃	Moving to MC08
47	37		**8/30**	**Sa**	MC08	Sampling ctd-LC01	Bathymetric Survey	Pali Seamount
48	38	1	**8/31**	**Su**		Sampling CB02,03,04	〃	
49	39	2	9/1	Mo		Sampling CB05,06,07,08	〃	
50	40	3	9/2	Tu		Sampling CB09,10,11,12	〃	
51	41	4	9/3	We		FDC Survey 01,02	〃	
52	42	5	9/4	Th		Sampling CB13,14,15	〃	
53	43	6	9/5	Fr		Sampling LC16,17 SSSSurvey 01	〃	
54	44	7	**9/6**	**Sa**		Sampling CB18,19,20	〃	Moving to MC09
55	45		**9/7**	**Su**	MC09		Bathymetric Survey	
56	46	1	9/8	Mo		Sampling ctd-LC01 Sampling CB02,03,04	〃	
57	47	2	9/9	Tu		Sampling CB05,06,07	〃	
58	48	3	9/10	We		Sampling CB08	〃	
59	49	4	9/11	Th		Sampling CB09,10	〃	
60	50	5	9/12	Fr		Sampling CB11,12,13	〃	
61	51	6	**9/13**	**Sa**		FDC Survey 01	〃	
62	52		**9/14**	**Su**			〃	Moving to MC10
63	53	1	**9/15**	**Mo**	MC10		Bathymetric Survey	
64	54	2	**9/16**	**Tu**		Sampling ctd-LC01 Sanpling CB02,03	〃	
65	55	3	9/17	We		Sampling CB04,05,06,07	〃	
66	56	4	9/18	Th		Sampling CB09	〃	
67	57	5	9/19	Fr		Sampling CB10,11,12	〃	
68	58	6	**9/20**	**Sa**		Sampling CB13,14,15,16	〃	
69	59	7	**9/21**	**Su**		FDC Survey 01	〃	
70	60	8	9/22	Mo		Sampling LC17,18 Sampling CB19,20	〃	
71	61	9	**9/23**	**Tu**		* Departure from the survey area		Sailing to Guam
72			9/24	We				Sailing to Guam
73			9/25	Th				Sailing to Guam
74			9/26	Fr		* Arrival in Guam		

* Date and Time are shown in Local Time

Chapter 2 Survey Methods

In 1997, the third fiscal year of the Third Phase of the five year SOPAC Program, topographical survey and other surveys relevant to the study of submarine mineral resources exploration were carried out, as planned, within the exclusive economic zone of the Federated States of Micronesia (Fig. 1-3-1). The target of the survey was cobalt-rich manganese crusts.

The survey was carried out in two segments, the first and the second half with a call at Pohnpei in between. The first half will be called Leg 1 and the second half Leg 2.

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, analyzed, date were interpreted, and the results were integrated into a report.

2-1 Selection of Seamounts

In selecting the seamounts, for the survey, we first prepared a topographic map of the zone above 2,500 m water depth referring to the ETOP05 Topographic Grid Data prepared by NOAA (USA) and extracted seamounts. By this method we located 39 seamounts including submerged islands with summits shallower than 2,000 m water depth. This number of seamounts, however, differ by the treatment of those on continuous oceanic ridges and those on oceanic plateaus. Of these 39 seamounts, 21 have summits shallower than 30 m water depth, namely rocks exposed at low tide and submerged islands.

About a dozen or more seamounts were further selected as candidates for the present investigation. Those with wide terraces were selected from the those with summits shallower than 30 m -low-tide rocks and submerged islands-and depth of the summits and size of the seamounts were considered for the normal seamounts.

During Leg 1, seamounts on oceanic plateaus on the western side were mainly studied, and isolated seamounts on the eastern side were mainly surveyed in Leg 2. During the survey, the location of the seamounts was confirmed by referring to the, "Satellite Bathymetric Survey of the Maritime Zone of the State of Yap FSM, June 1996; Ministry of Foreign Affairs, French Government," and "Smith, W.H.F. and D.T. Sandwell, Global Seafloor Topography from Satellite Altimetry and Ship Depth Soundings, submitted to Science, April 7, 1997". The seamounts surveyed were numbered in the order of survey MC1 ~ MC10.

2-2 Survey Methods

Survey of each seamount consisted mainly of the following work; topographic survey for clarifying the detailed seafloor topography Appendix Figures 1 (1) to (10), sampling by chain back dredge (CB) or arm dredge (AD) 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 nSBP 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 for some seamounts in order to understand the micro-topography and the sediments of the seafloor.

The duration of the survey for each seamount was five to nine days depending on the size of the seamount and the water depth of the summit. *1

2-3 Numbering

The numbering system used is as follows.

For sampling points: Year-S-Area N o.-Sample No.

S denotes SOPAC, areas numbered sequentially from MC01 to MC10,

Samples numbered sequentially from 01 for each area.

Examples: 97SMC01CB01 (CB survey)

97SMC01AD03 (AD survey)

97SMC01LC02 (LC survey)

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

Samples numbered sequentially from 01 for each area.

Example: 97MC01SSSS01

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

Example: 97SMC01FDC01

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*1 Only two track lines for topographic survey were possible for Seamount MC01 because of weather conditions. Therefore, only data of these two track lines are reported and analysis and interpretation have not been carried out.

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. And the coordinates used for the measurement was WGS84.

2-5 Acoustic Survey

The seafloor topographic survey was carried out by MBES and the main track line interval was set at 2.0 miles. Auxiliary lines were set between the main lines for shallow (under 2,000 m) zones. We did not enter extremely shallow waters such as under 1000 m depth or 1nm from the shore. 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 100 m above the seafloor and the data were obtained for a width of 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 camera. The observation lines were set mostly at the peripheries and downward along 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 from topographic maps, MBES acoustic reflection intensity maps and SBP results. Also sampling was designed to represent the total seamount by dispersing the sites relatively evenly.

2-8 CTD Measurements

CTD measurement was carried out for each area in order to determine the sonic velocity necessary for MBES. This was done simultaneously with LC sampling.

Water depth was calculated from CTD values on the FDC for positioning the towed vehicle.

2-9 Processing and Analysis of Survey Data

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

Manganese oxides samples were assayed and studied optically and the rock samples were chemically analyzed, studied optically and the mineral composition as well as the textures were determined. Microfossils were identified from sediment samples.

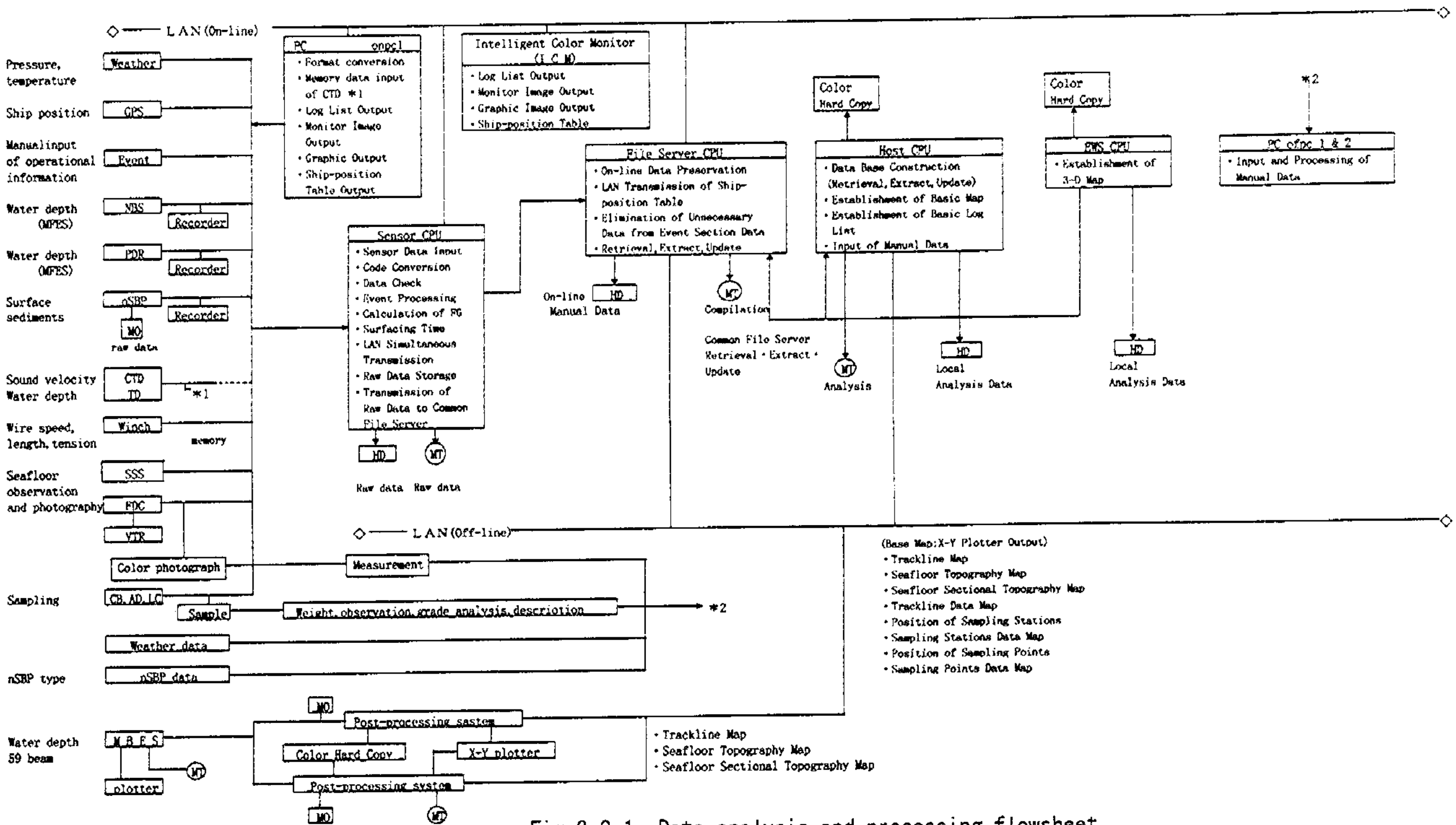

Fig. 2-9-1 Data analysis and processing flowsheet

Chapter 3 Results the Survey

3-1 Topographic Survey

(1) Outline of topography

The Federated States of Micronesia (FMS) is located to the north of the equator in the western Pacific, and most of the islands belong to the Caroline Islands which are widely distributed in the east-west direction, but the western islands belong to the Yap Islands. To the southwest of the Yap Islands are the Palau Islands and to the northeast are the Mariana Islands. Also the Marshal Islands exist to the east of the Caroline Islands (Fig. 3-1-1).

In the survey area, there are many oceanic islands and atolls and many seamounts and guyots. The geology of the western seafloor of the survey area is quite complex with trenches, troughs, oceanic ridges, oceanic plateaus, and other structures. The major structures are; NNE-SSW trending Mariana Trench, WNW-ESE trending Caroline Ridge and Sorol Trough, and E-W trending Eauripik Trough. The islands and the seamounts generally form a belt in the east-west direction because they occur mostly on the ridges and plateaus extending in the WNW-ESE ~ WSW-ENE direction. On the other hand, the islands and the seamounts in the eastern part of the survey area are scattered independently in the WNW-ESE direction.

The location of the ten surveyed parts (MC01 ~ MC10) are as follows from the west. MC01 and MC02 are in the western part of the Caroline Ridge, MC03 is immediately south of the Eauripik Trough, MC04 is immediately south of the Sorol Trough, MC05 and MC06 are to the south of the central part of the Caroline Ridge, MC10 is at the northern margin of the central part of the Caroline Ridge, MC07 and MC09 are in the eastern part f the Caroline Ridge, and MC08 is to the north of the eastern part of the Caroline Ridge. The above ten surveyed areas extend more widely in the east-west direction (139° E ~ 158° E) than in the north-south direction (4° N ~ 11° N).

(2) Classification and topographic division of seamounts

The ten areas targeted for survey were named consecutively from MC01 to MC10. The types of these seamounts was divided as listed in Table 3-1-1. The topography of these seamounts were further divided into the summit and the slope as shown in Table 3-1-2 and Figure 3-1-2. The water-depth distribution of the summit and slope, however, differs by individual seamounts because the division is based on topographic gradient distribution map.

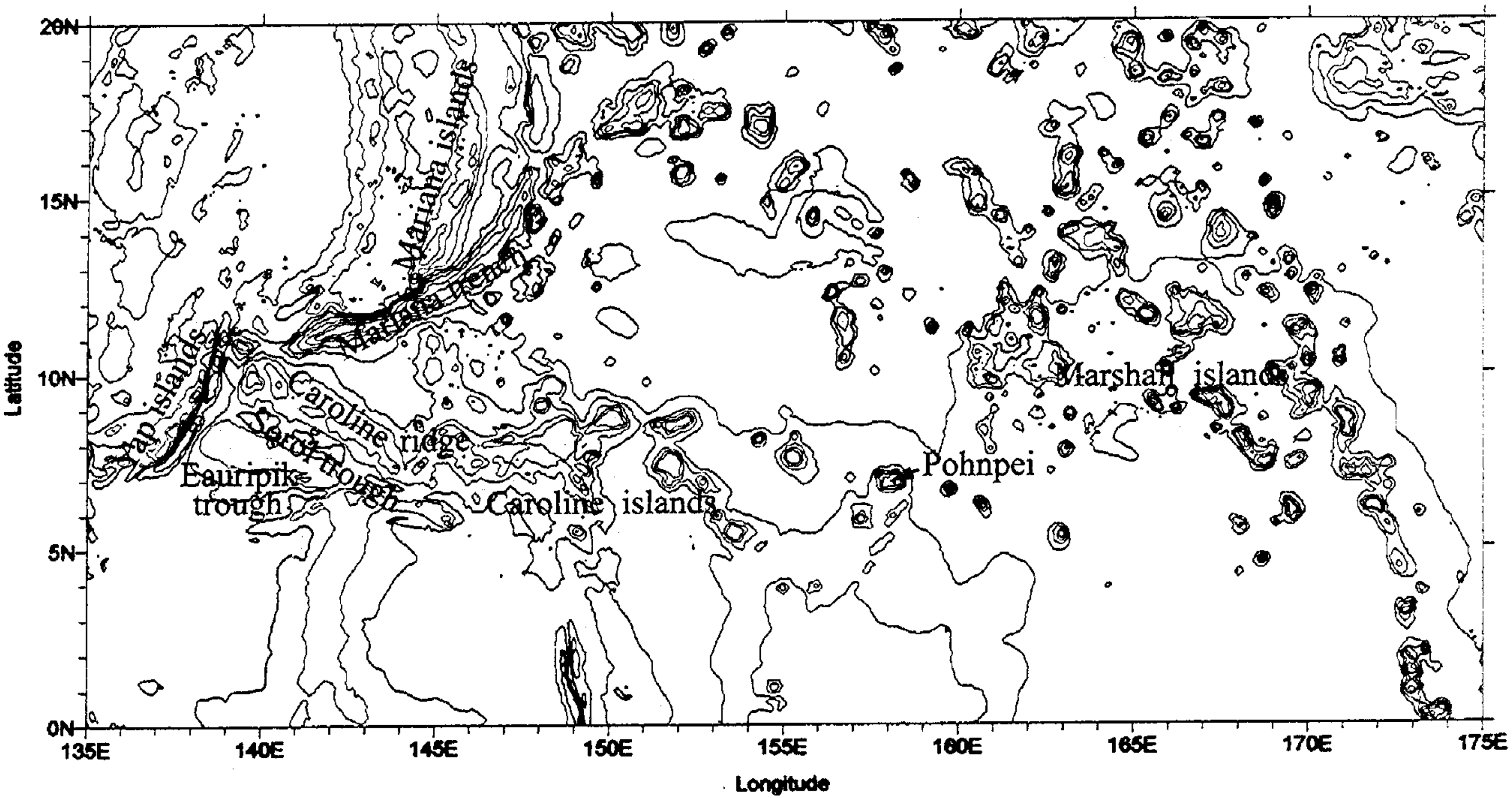

Fig. 3-1-1 Structural map around the survey area

Table 3-1-1 Classification of seamount topographic type

Classification	Morphological Characteristics
Table Seamount (Guyot)	The summit is flat and horizontal.
Pointed Seamount	The summit is steeple-shaped or ridge-shaped.

Table 3-1-2 Classification of seamount topography

Topographic division		Topographic Characteristics
Summit	Central part	Flat to gentle gradient part summit center.
	Periphery	Transitional zone from summit center to upper slope.
Slope	Upper part	Steep and rugged part of slope.
	Middle part	Between upper and lower slope, gradient intermediate.
	Lower part	Middle to lower slope with gentle gradient.
Seamount foot		Transitional part from lower slope to ocean floor.

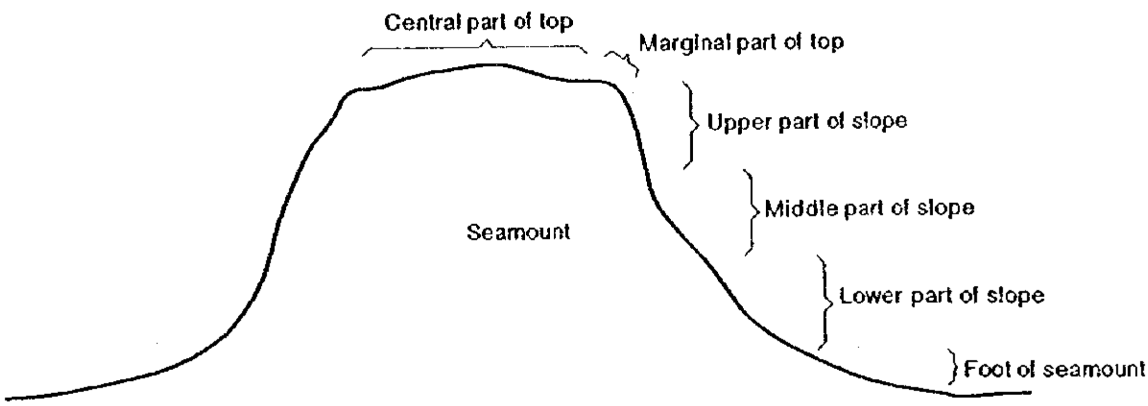

Fig. 3-1-2 Schematic model of seamount topographic classification

(3) Seamount topography

The topographic division of individual seamounts and the statistics of the slope gradient are laid out in Table 3-1-3 and the characteristics of each seamount in Table 3-1-4. Also the seamounts are classified as follows.

Guyots	MC07, MC08, MC10
Pointed seamounts	MC09 (south)
Oceanic ridge	MC03, MC04
Shoal	MC05
High-relief summit	MC06, MC09 (north)
Part of oceanic plateau	MC02

The characteristics of these nine seamounts are summarized as follows.

Seamount with largest slope area	MC10 (south) (2,205 km² above 3,000 m depth)
Seamount with smallest slope area	MC09 (north) (119 km² above 3,000 m depth)
Largest seamount	MC10 (south) (NE-SW 43 km × NW-SE 43 km)
Smallest seamount	MC08 (south) (E-W 11 km × N-S 9 km)
Seamount with shallowest summit	MC04 (west) (10 m deep)
Seamount with deepest summit	MC09 (north) (2,032 m deep)
Seamount with largest flat summit	MC02 (1,134 km² summit) MC10 (south) (1,067 km² summit)
Seamount with largest relative height	MC09 (south) (4,000 m)
Seamount with smallest relative height	MC02 (2,400 m)

Three dimensional seafloor maps of seamounts are shown in Figures 3-1-3 (2) ~ (10), seafloor hypsometric tint maps in Appendix Figures 2 (1) ~ (10), and topographic gradient maps in Appendix Figures 3 (2) ~ (10).

1) MC01

The survey target in MC01 area was the terrace extruding southward from the Ulithi Island at 3,000 m water depth. Only two track lines for topographic and acoustic survey were possible due to weather conditions and the results are laid out in Appendix Figure 2 (1). This figure was prepared by using as the base map the estimated isobathymetric map of the " French Government, Ministry of Foreign Affairs: Satellite Bathymetric Survey of the Maritime Zone of the State of Yap FMS, June 1996 " , and by laying the presently acquired data over this base map.

Table 3-1-3 Topographic Division and Gradient of Seamounts

Seamount	Division	Water depth range (m)	Slope area (km²)	Average gradient (°)	Minimum gradient (°)	Maximum gradient (°)	Frequency distribution of gradient (%)			
							0-10	10-20	20-30	30<
MC02	Summit	<1,600	1134	3.4	0.0	51.8	92.5	4.0	2.1	1.5
	Upper slope	1,600<3,300	1838	7.2	0.0	58.6	82.7	7.8	3.9	5.7
	Middle slope	3,300<	419	6.3	0.0	47.6	84.0	10.5	4.5	1.1
	Lower slope									
MC03	Summit	<2,000	625	14.1	0.2	62.2	44.4	32.5	13.5	9.7
	Upper slope	2,000<2,500	406	16.4	0.3	55.3	34.3	34.2	19.7	11.8
	Middle slope	2,500<3,000	774	13.6	0.1	59.4	43.6	34.6	15.0	6.9
	Lower slope	3,000<	5871	5.0	0.0	57.1	84.3	10.3	4.1	1.3
MC04 (E)	Summit									
	Upper slope	<2,000	379	11.9	0.1	53.2	53.2	29.0	13.3	4.5
	Middle slope	2,000<3,000	775	11.3	0.0	55.3	54.5	26.7	14.4	4.4
	Lower slope	3,000<	102	12.0	0.2	49.4	46.8	40.6	9.5	3.2
(W)	Summit									
	Upper slope	<2,000	563	15.9	0.3	60.4	32.6	40.6	16.7	10.1
	Middle slope	2,000<3,000	1070	10.5	0.0	55.3	55.8	31.9	10.2	2.0
	Lower slope	3,000<	909	6.6	0.0	49.4	79.8	14.5	4.4	1.3
MC05	Summit	<1,500	504	14.3	0.1	50.2	44.4	26.6	20.3	8.7
	Upper slope	1,500<2,000	230	16.9	0.4	45.5	17.0	51.3	27.4	4.3
	Middle slope	2,000<3,000	686	15.2	0.2	47.5	25.6	49.8	21.7	3.0
	Lower slope	3,000<	3814	6.4	0.0	52.4	81.2	14.8	3.2	0.8
MC06	Summit									
	Upper slope	<2,000	240	17.9	0.2	53.6	20.2	40.5	30.1	9.3
	Middle slope	2,000<3,000	514	15.6	0.4	50.2	26.5	47.0	21.3	5.2
	Lower slope	3,000<	742	9.9	0.1	46.0	60.9	27.0	9.9	2.3
MC07	Summit	<2,000	278	6.3	0.1	29.5	83.2	12.1	4.6	0.0
	Upper slope	2,000<2,500	519	7.5	0.1	47.1	78.8	15.2	4.7	1.2
	Middle slope	2,500<3,000	198	16.6	0.1	50.2	37.0	22.8	26.6	13.7
	Lower slope	3,000<	831	5.1	0.0	47.3	82.4	11.9	5.1	0.7
MC08 (N)	Summit	<2,100	178	5.7	0.1	29.8	86.7	11.4	1.9	0.0
	Upper slope	2,100<3,000	196	18.9	0.4	36.6	21.7	24.1	47.7	6.5
	Middle slope	3,000<3,500	164	17.2	0.7	48.8	13.2	53.5	31.7	1.7
	Lower slope	3,500<5,000	993	12.2	0.1	47.5	39.9	45.7	14.1	0.3
(S)	Summit	<2,100	38	10.5	0.2	31.2	58.9	26.0	14.8	0.3
	Upper slope	2,100<3,000	91	20.4	0.9	35.5	7.1	37.3	51.0	4.6
	Middle slope	3,000<3,500	92	17.9	1.0	38.2	14.7	46.0	36.4	2.9
	Lower slope	3,500<5,000	533	14.7	0.0	38.2	27.1	50.9	21.3	0.8
MC09 (N)	Summit	<3,000	154	16.0	0.6	33.6	23.1	44.6	31.7	0.6
	Upper slope	3,000<3500	209	16.3	0.2	36.3	24.3	41.0	32.7	2.0
	Middle slope	3,500<4,000	213	16.9	0.4	34.4	20.8	42.1	35.1	1.9
	Lower slope	4,000<4,500	586	10.3	0.0	32.2	56.7	31.8	11.4	0.1
(S)	Summit									
	Upper slope	<2,000	26	27.3	4.6	37.1	1.9	10.2	49.7	38.2
	Middle slope	2,000<3,000	93	22.3	1.6	40.2	4.8	25.5	61.7	8.0
	Lower slope	3,000<4,500	1483	7.0	0.0	43.4	74.5	18.5	6.5	0.5
MC10 (N)	Summit	<2,000	334	5.8	0.0	46.2	85.2	10.0	3.7	1.0
	Upper slope	2,000<2,500	129	19.9	0.9	47.3	19.8	25.5	41.5	13.2
	Middle slope	2,500<3,000	205	14.9	0.1	48.5	30.8	39.5	28.0	1.7
	Lower slope	3,000<4,000	1572	6.6	0.1	41.4	80.8	13.8	5.1	0.3
(S)	Summit	<2,000	1067	2.6	0.0	34.5	97.6	1.7	0.6	0.1
	Upper slope	2,000<2,500	316	13.7	0.3	43.2	39.6	37.0	20.1	3.2
	Middle slope	2,500<3,000	822	9.5	0.0	45.2	63.1	26.9	8.5	1.5
	Lower slope	3,000<4,000	1479	9.1	0.1	44.1	66.2	25.6	7.3	0.9

Table 3-1-4 Characteristics of Seamount

Seamount	Location	Type	Shallowest Depth (m)	Base Depth (m)	Relative Height (m)	Seamount size (above 300m) long axis × short axis (km) long axis direction	Seamount characteristics	Summit area (k m²)	Slope area (k m²) (above 3,000m)
MC02	9° 04′ N 141° 28′ E	Part of plateau	1,080	3,500	2,400		Steep slope extends E-W in the north. Summit covered by sediments. Pinnacles in SE part of summit.	1,134	1,838 (above 3,300m)
MC03	6° 18′ N 141° 37′ E	Ridge	510	3,900	3,400	80×20 ENE−WSW	Foot of seamount oval−shaped . NEN−SWS ridges and pinnacles on summit.	625	1,180
MC04 (N)	6° 12′ N 144° 45′ E	Ridge	950	3,800	2,800	40×40 NW−SE	Ridges extend NW−SE. NE side of ridges steep. Many small depressions in SW.		1,154
(E)	6° 15′ N 144° 22′ E	Ridge	100	3,800	3,700	60×30 E−W	Ridges extend E−W with 2 peaks. N side of ridges steep near summit.		1,633
MC05	5° 31′ N 149° 13′ E	Shoal	190	4,000	3,800	60×30 E−W	Ridges extend in 3 directions in triangle. Many NW−SE structures on NE side.	504	916
MC06	4° 23′ N 147° 58′ E	High relief seamount	740	3,500	2,800	70×40 ENE−WSW	Seamount divided into 3 by prominent NW−SE structures.		460
MC07	6° 05′ N 157° 26′ E	Guyot	1,423	3,800	2,400	37×20 NW−SE	Caldera depression on W side. Seamount part of somma. Sediments exist.	278	995
MC08 (N)	10° 20′ N 156° 27′ E	Guyot	1,583	5,500	3,900	24×15 N−S	Seamount piedmont nearly circular. Summit oriented N−S with sediment cover.	178	374
(S)	10° 16′ N 156° 27′ E	Guyot	1,692	5,500	3,800	11×09 E−W	Nearly circular piedmont. Sediments on summit, but bedrock exposure in shallowest part.	38	129
MC09 (N)	8° 21′ N 155° 26′ E	High relief seamount	2,032	5,100	3,100	15×13 NW−SE	Many pinnacles on summit, almost no sediments.	154	154
(S)	8° 06′ N 154° 58′ E	Pointed seamount	1,096	5,100	4,000	15×08 E−W	Long axis extend E−W. Oceanic plateau in S.		119
MC10 (N)	10° 10′ N 148° 16′ E	Guyot	1,422	4,800	3,300	33×19 NE−SW	Summit has dome structure, sediments observed, but rock exposures on shallowest part and eastern periphery of summit.	334	668
(S)	9° 45′ N 148° 20′ E	Guyot	1,560	4,800	3,200	43×43 NE−SW	Typical guyot. Dome summit with sediment cover, seafloor smooth.	1,067	2,205

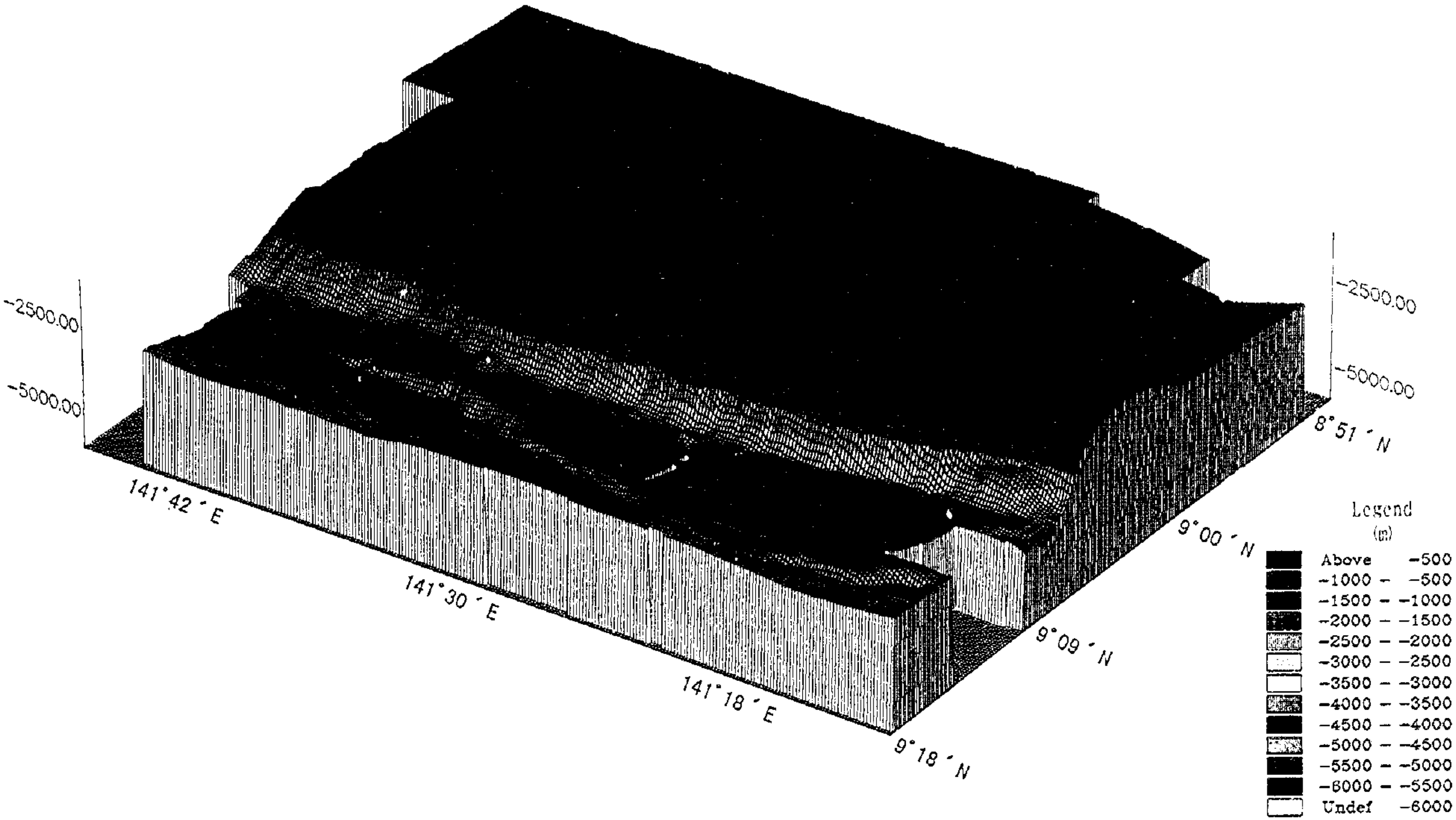

Fig. 3-1-3(2) Bird's eye view of bathymetry of MC02 area

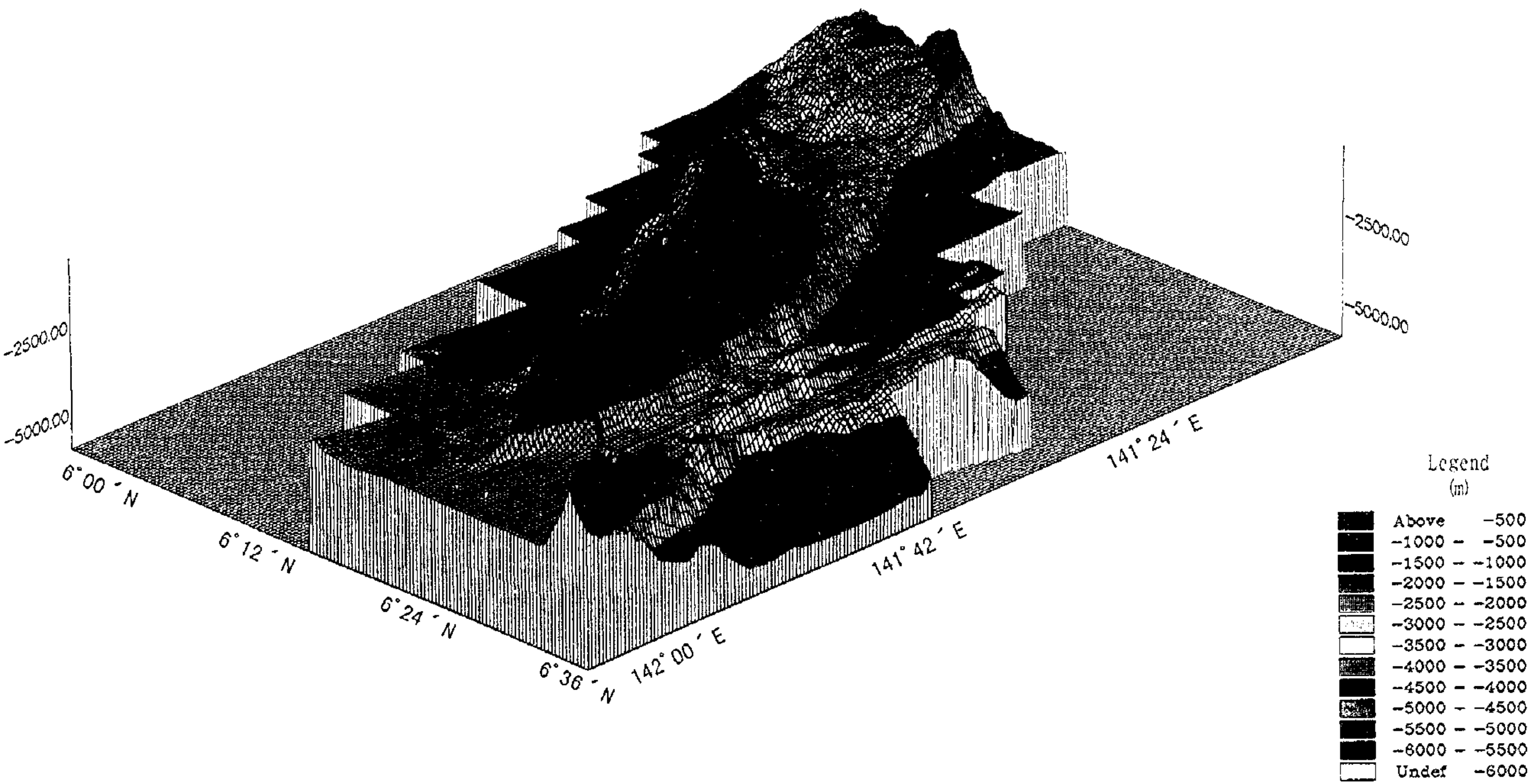

Fig. 3-1-3(3) Bird's eye view of bathymetry of MC03 area

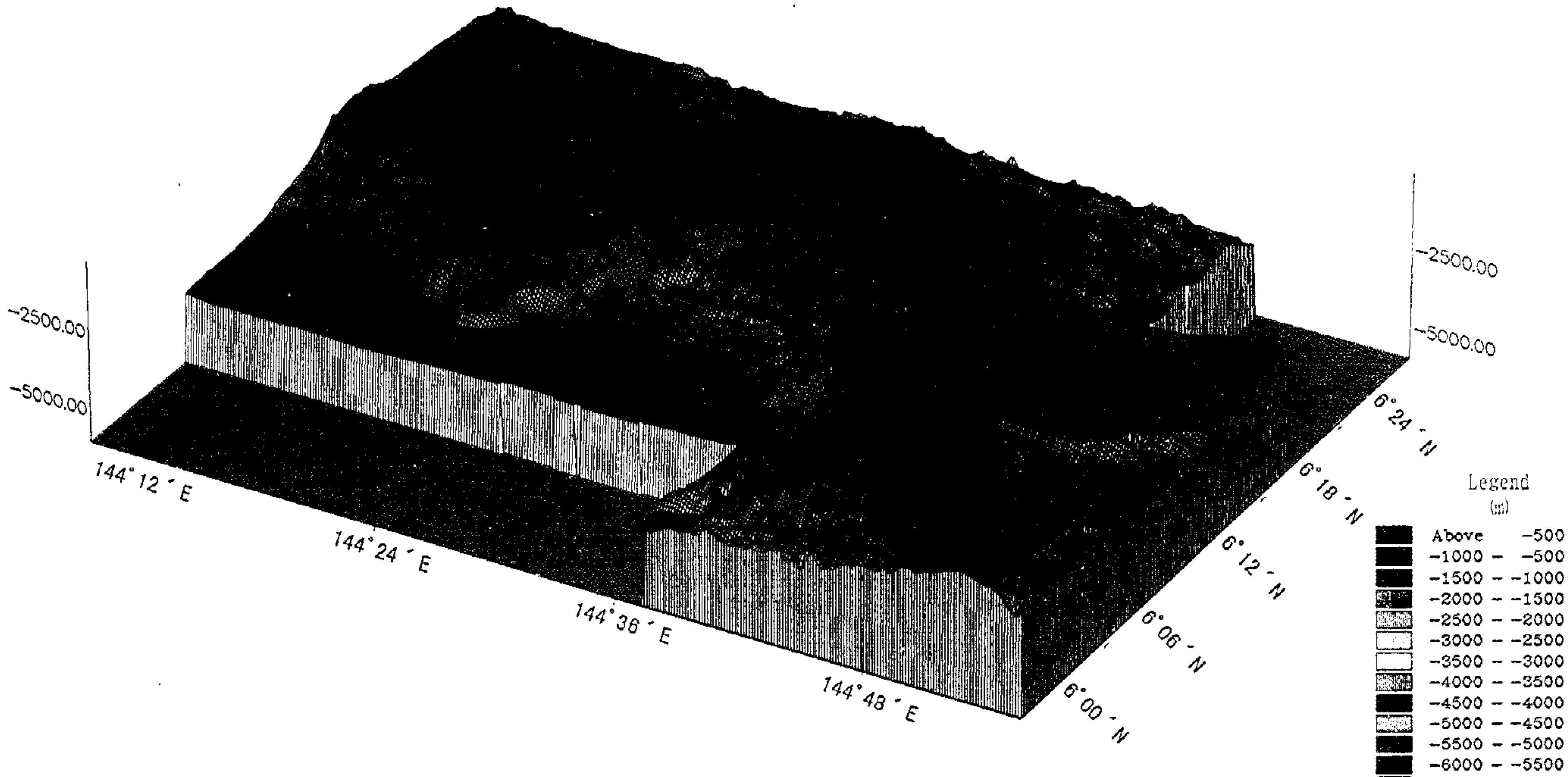

Fig. 3-1-3(4) Bird's eye view of bathymetry of MC04 area

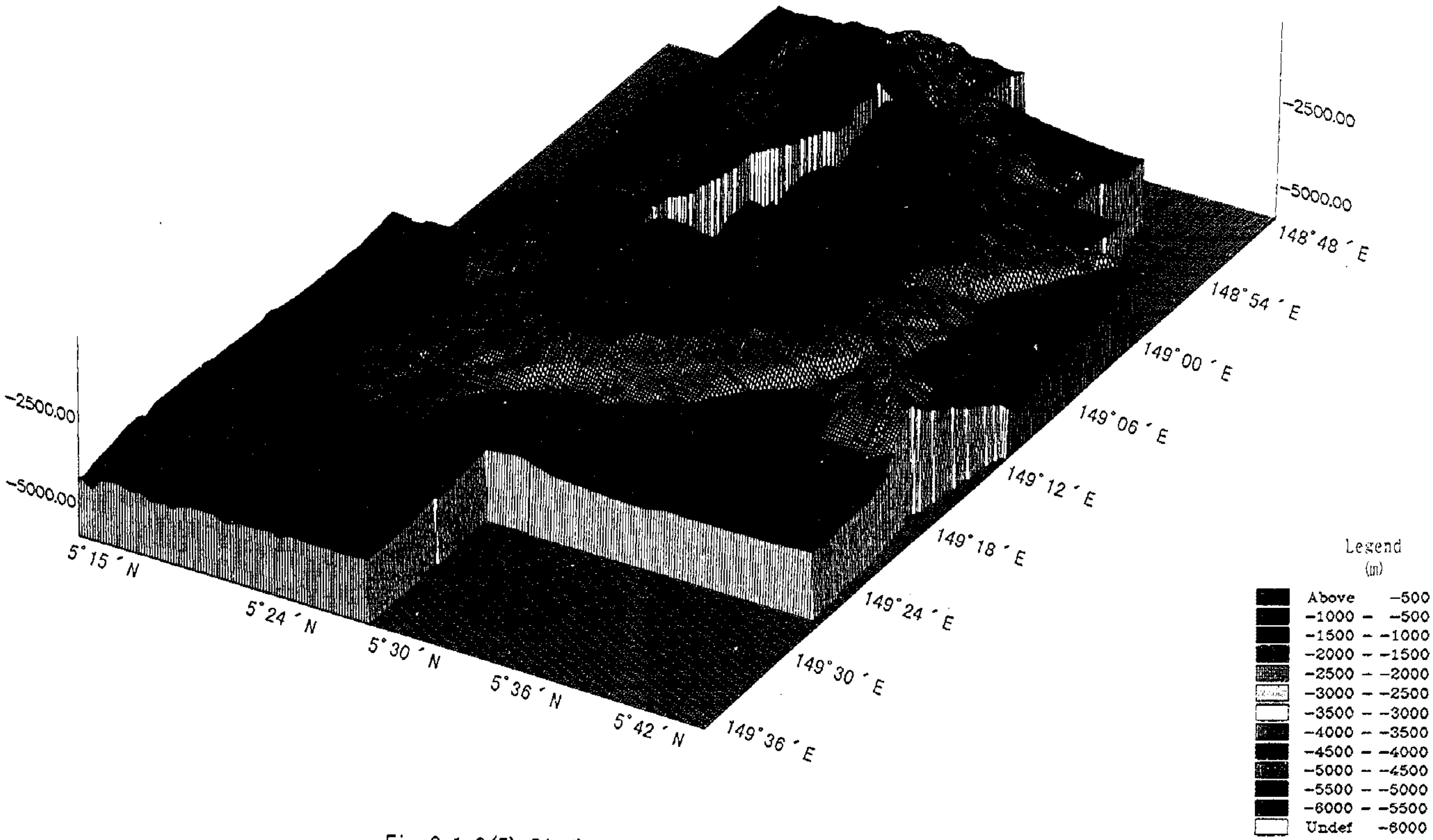

Fig. 3-1-3(5) Bird's eye view of bathymetry of MC05 area

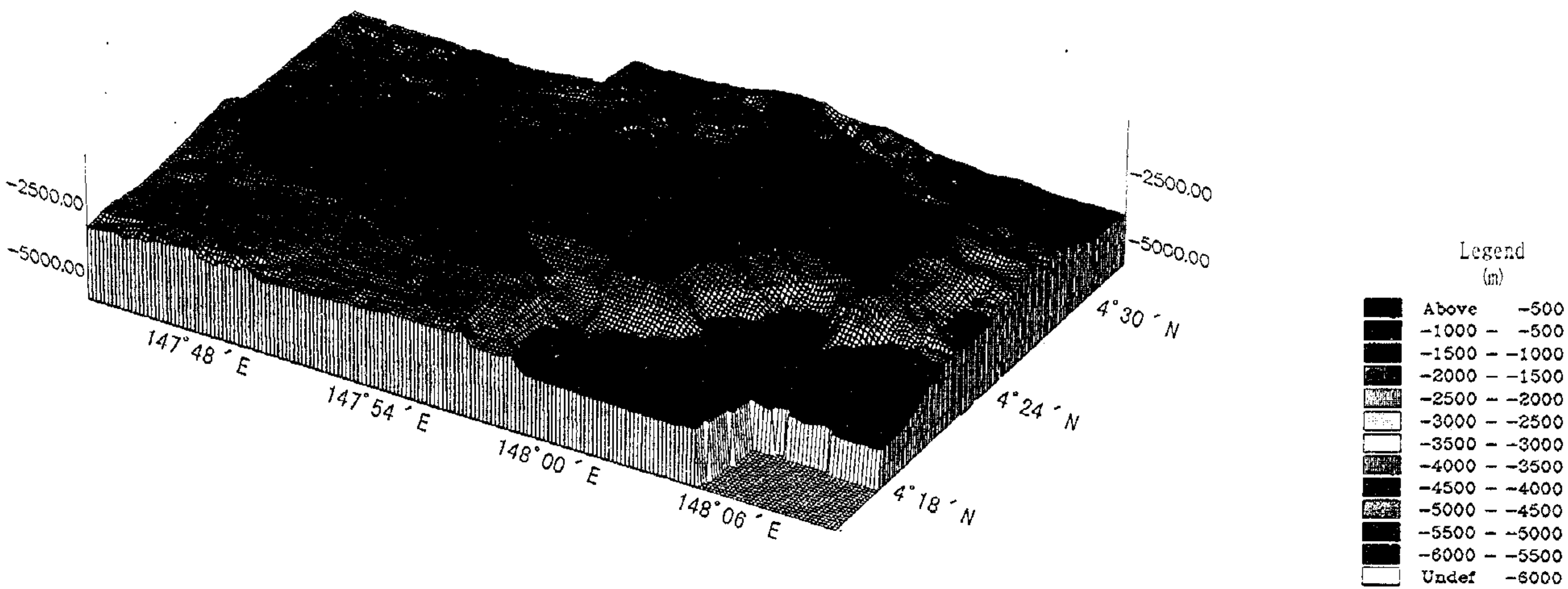

Fig. 3-1-3(6) Bird's eye view of bathymetry of MC06 area

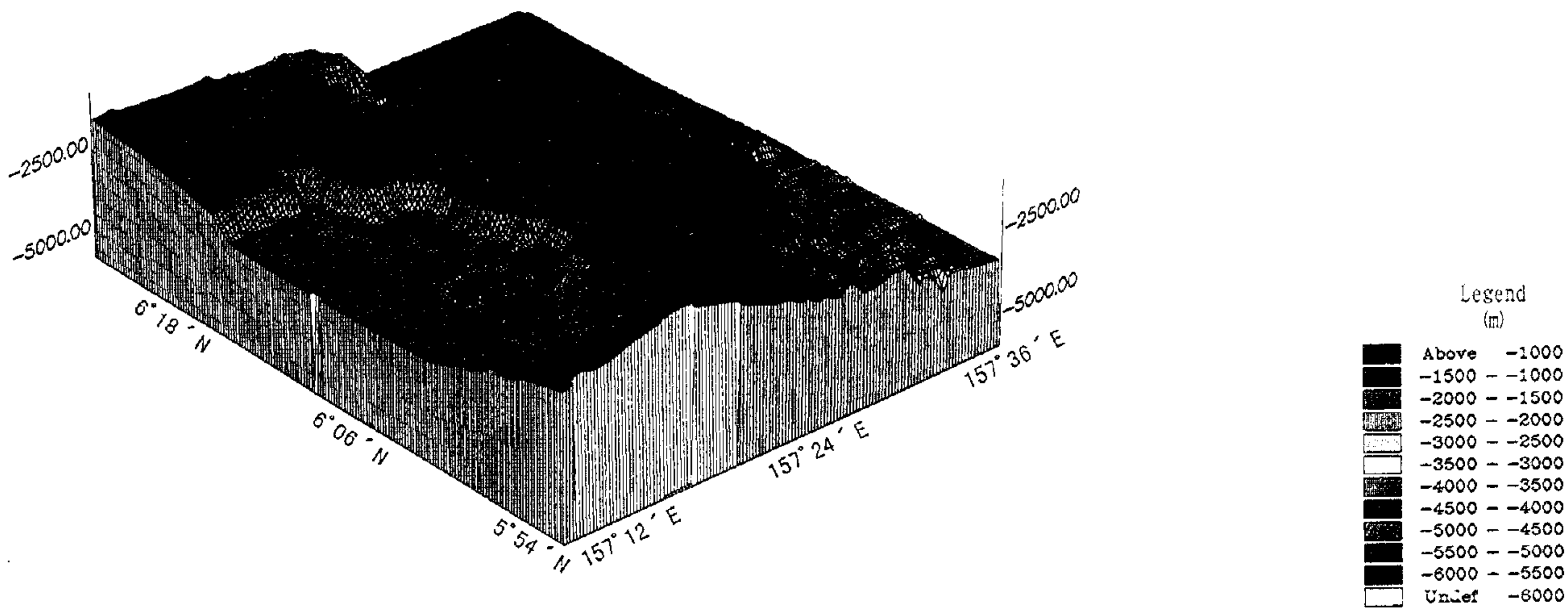

Fig. 3-1-3 (7) Bird's eye view of bathymetry of MC07 area

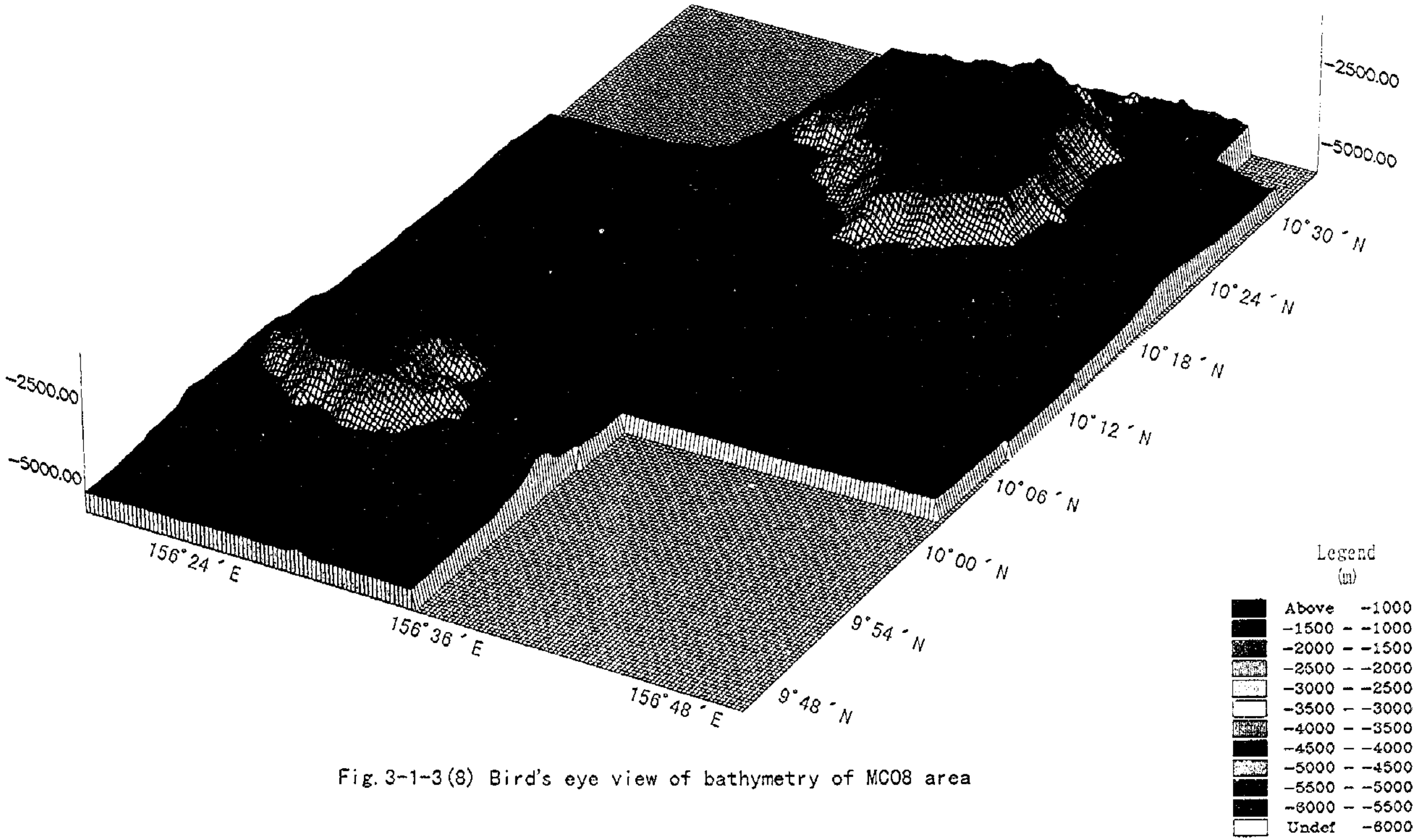

Fig. 3-1-3 (8) Bird's eye view of bathymetry of MC08 area

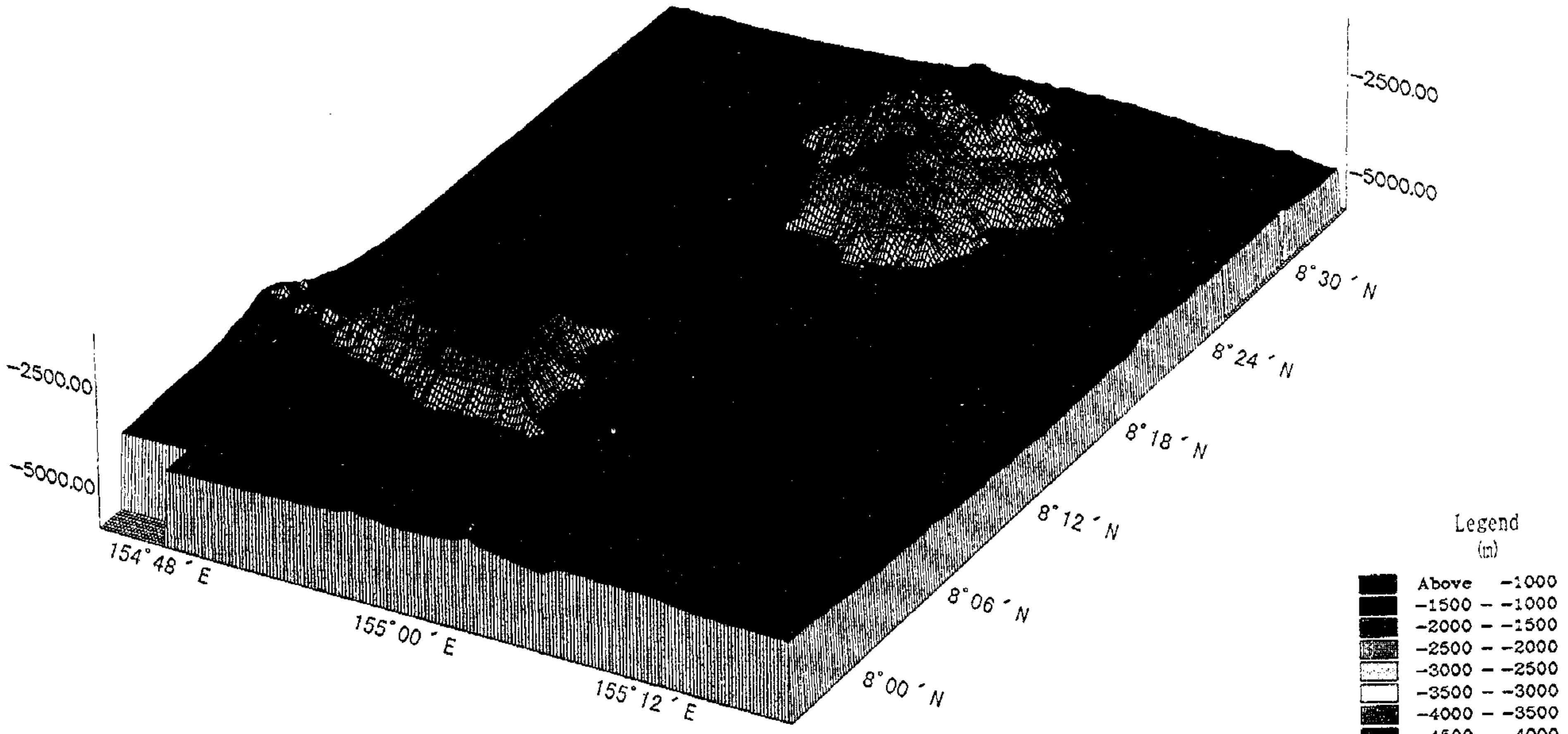

Fig. 3-1-3(9) Bird's eye view of bathymetry of MC09 area

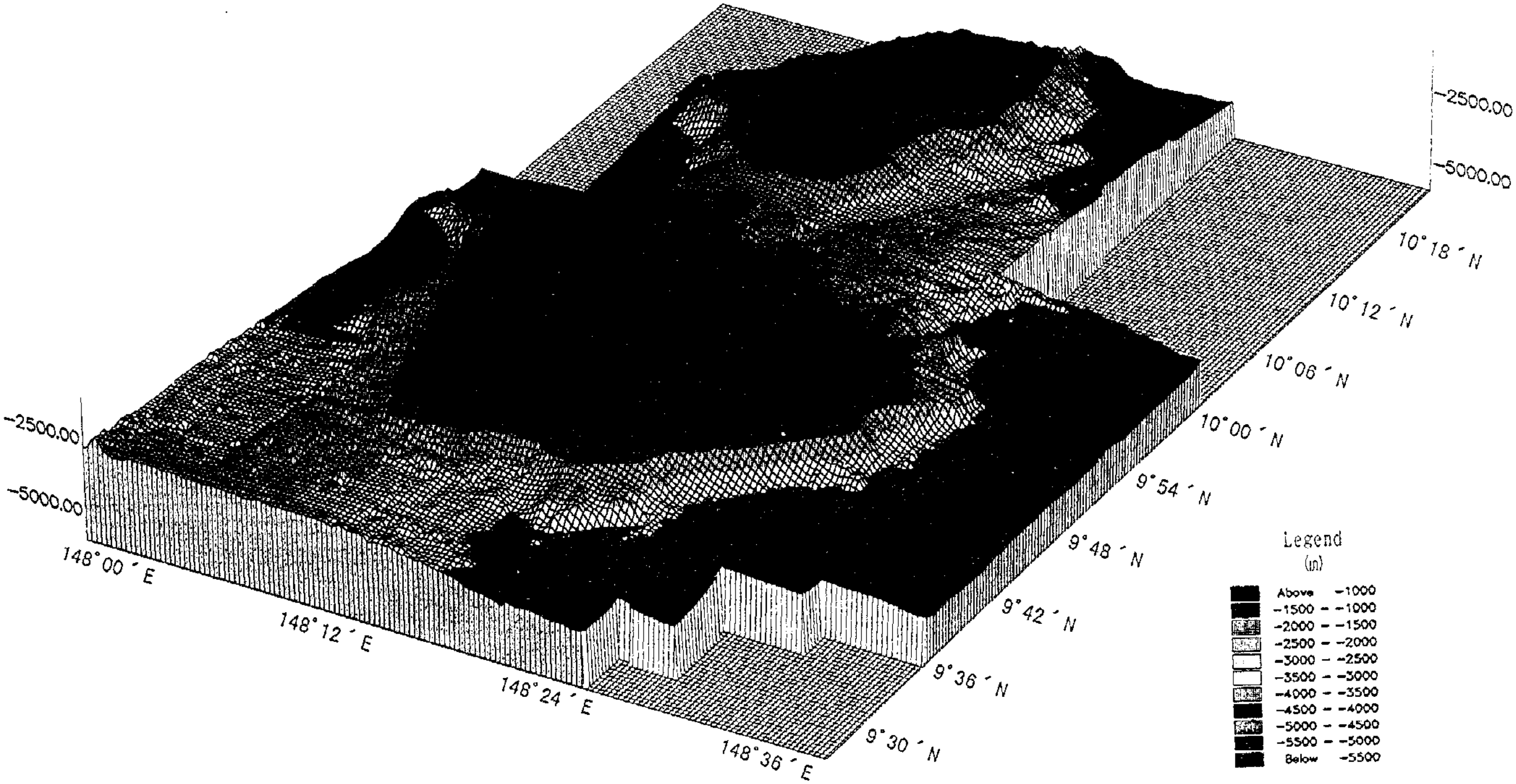

Fig. 3-1-3(10) Bird's eye view of bathymetry of MC10 area

This terrace has a long axis extending in the ENE–WSW direction, and the size of the seamount is 40 km × 20 km (above 2,500 m water depth). The deepest part of the track line is 800 m.

2) MC02

This forms a part of an east–west rending oceanic plateau and its relative height from the base is 2,400 m. A steep northward slope extends in approximately east–west direction for a long distance. The water depth of this slope ranges from 1,400 to 3,300 m with relative height of about 2,000 m. Maximum gradient is 59° and the average exceeds 35°. In the southeastern part of the summit, there are pinnacles of about 500 m relative height arranged in arc. There is a gentle southward slope of average 2° in the central part of the summit and it occupies the major part of the summit. The shallowest part of this seamount is the pinnacles in the southeast with 1,080 m water depth.

3) MC03

This seamount is a part of an oceanic ridge extending in the WNW–ESE direction. It has an oval shape. The summit has rugged relief and the topography is complex. There are peaks in the eastern, central, and western parts of the summit, the western part showing NNE–SSW trending ridge, the central and the eastern parts have pinnacles. The areas between these peaks are relatively flat. The shallowest part is in the west with 510 m water depth. The relative height from the base is 3,400 m.

The average gradient of the upper to middle slope is relatively steep at 16° and 14° respectively and it decreases to 5° in the lower part. The northern slope near the summit is steeper than that of the southern slope.

4) MC04

Surveyed seamounts are divided by longitude 144° 40' E, into two bodies named eastern seamount and westrn seamount.

・ Eastern seamount

A narrow ridge extends in the NW–SE direction and there is a large pinnacle on the northern side. The seamount as a whole is a part of an oceanic ridge. The shallowest part is the pinnacle with 950 m depth and a relative height of 2,800 m. On the southwestern side, there are some ridges protruding southwestward.

The average gradient of the slope is about 12° for upper, middle, and lower parts. The northeastern slope of the ridge is steeper than the southwestern side. But the seafloor deeper than 2,900 m is very flat. Many small depressions are observed from the middle to the lower part of the southwestern slope.

・ Western seamount

This forms a part of an oceanic ridge and a narrow east-west extending ridge is dislocated in the north-south direction in the central part. There is a peak in both eastern and western parts of the summit and the shallowest part is in the west with 100 m of water depth. The relative height is 3,700 m from the base. In the west, a ridge protrudes southward characteristically in terrace form.

The average gradient of the slope decreases downward from 16 ° in the upper part through 11 ° in the middle to 7 ° in the lower part. Northern slope is steeper than that of the south.

5) MC05

This seamount has long axis in the east-west direction and it forms an isosceles triangle with the apex in the north. The peak is believed to be near the sea surface. Long ridges extend in the southwest and southeastward, and the lower slope on the southeastern side protrudes widely forming a terrace. NW-SE trending linear structures are observed from the lower slope to the foot of the seamount on the northeastern side.

The upper slope is relatively steep with 17 ° average, and becomes gentle downward with 15 ° in the middle and 6 ° in the lower part.

6) MC06

This seamount has an ENE-WSW trending long axis and the size is relatively small with 40 km × 25 km. It is divided into three parts by two NW-SE trending structures and they each have a peak. The shallowest part is in the western part and is 740 m deep with a relative height of 2,800 m from the base.

The average gradient is 18 ° , 16 ° , 10 ° for the upper, middle and lower slope respectively, showing similar gradient from the upper to the middle slope.

7) MC07

There is a caldera-type depression (30 km × 30 km) at 6 ° 08' N., 157 ° 03' E., and there are four connected seamounts in the east, west, south, and north surrounding this depression. The southern one is an island. MC07 arc is at the eastern side and has an arc topography as if it is a part of a somma rather than an isolated seamount. The shallowest part of these seamounts excluding the extended parts of the southern island is 1,423 m deep and the relative height from the central depression is 1,700 m and that from the outer seafloor is 2,400 m. Many pinnacles are observed on the summit and also pinnacles are aligned linearly at the border with the southern seamount. The summit is covered by sediments with the exception of the pinnacles and the border to the southern seamount.

The average gradient is 8 ° , 17 ° , and 5 ° for the upper, middle and lower slope. Thus the slope is gentle as a whole. The gradient of the caldera-type depression and the northeastern base is also gentle with less than 5 ° .

8) MC08

The seamount on the northern side is an isolated guyot with its center at 10 ° 20' N., 156 ° 42' E. The shallowest part of the summit is 1,583 m deep with a relative height of approximately 3,900 m from the base. The long axis of the rectangular summit is 18 km in north-south and the short axis 15 km and the areal extent of the part above 2,100 m depth is 178 km ^{2} . The gradient of the summit is less than 5 ° and it is covered by sediments. Pinnacles occur along the western periphery of the summit and the bedrocks is exposed in the vicinity.

The average gradient of the upper slope is 19 ° , the middle 17 ° , and the lower slope is 12 ° , the slope becomes gentle downward. The gradient map, however, indicates that the eastern slope is steeper than others and there are no notable ridges on this side. On the other hand, the northwestern and southwestern slopes are relatively gentle and the southwestern slope with three significant ridges is particularly gentle.

Also there is a nearly circular guyot 30 nm southwest of MC08. This, however, is smaller with a summit of 38 km ^{2} . Its shallowest part is 1,692 m deep and the relative height is 3,700 m. Sediments are observed on the summit, but bedrock exposures are also found near the shallowest part above 1,800 m of water depth.

9) MC09

There are two seamounts here, one in the northern side and the other in the southern side. Both were surveyed.

- Northern seamount

This is a guyot with nearly circular base. This seamount is different from other guyots, however, that it is not covered by sediments. Namely there are many pinnacles and the bedrock is exposed. Because of this, the summit has an extremely rugged relief and it gradient is very steep for a summit at 16 ° . The shallowest part is 2,032 m deep, and the relative height is about 2,900 m and this is the deepest seamount in the present survey area. If we consider the part above 3,000 m as the summit, it is 119 km ^{2} .

The gradient of the upper slope is 16 ° , middle slope 17 ° , and the lower slope 11 ° . Compared to the western side, the lower slope on the eastern to the southern side is particularly gentle and many pinnacles are found here.

・ Southern seamount

This is a pointed seamount on oceanic plateau topography. Its long axis extends in east–west direction, a narrow ridge extends in northeast and southwest direction on the eastern side and general outline has an arrow head shape. The size of the whole seamount is small, but the depth is less than that of the northern seamount with 1,096 m at the summit and the relative height is 4,000 m.

The average gradient of the upper and middle slope is 27°, and 22° respectively. It has a relatively steep slope. Thus the seamount as a whole is not covered by sediments and the bedrock is exposed.

10) MC10

This is a typical guyot. The part above 3,000 m depth is 43 km × 43 km and has a triangular shape with the base on the northeastern side. The southwestern apex of this triangle forms the saddle continuing to seamounts to the southwest. The summit above 2,100 m gently rises to the top in a dome structure, and it is entirely covered by sediments without any notable relief. The average gradient of the summit is 3°, and the shallowest part is 1,530 m deep. The depth of the base is 4,600 m on the eastern side and the relative height here is 3,300 m. On the western side of the seamount, the lower slope continues to the foot of the seamount to the southwest. The relative height of the western side from this foot of the other seamount is about 2,000 m. Therefore, the slope on the western side is more gentle than that on the eastern side.

There is another guyot to the north with similar summit depth and relative height to MC10. The size, however, of this northern one is smaller with 30 km long axis (NE–SW) and 20 km short axis (NW–SE). Thus the slope is steep. Sediments are observed on the summit, but bedrock is exposed at the shallowest part. Also the bedrock is exposed at the eastern periphery of the summit.

3–2 MBES Acoustic Reflection Intensity Distribution

MBES acoustic reflection intensity from the seafloor was mapped. The distribution of the acoustic reflection from each seamount is shown in Figures 3–2–1 (1) ~ (10). In these maps, high acoustic reflection intensity is expressed in black (dark color) and the low intensity in white (pale color).

In these acoustic reflection intensity maps, the dark colored parts are correlated to bedrock exposure, and the pale parts to unconsolidated sediments. Also the degree of the color tone is believed to vary in accordance to the proportion of the unconsolidated material, the grain–size, and the occurrence.

The MBES acoustic reflection intensity distribution map of the seamounts show the following facts.

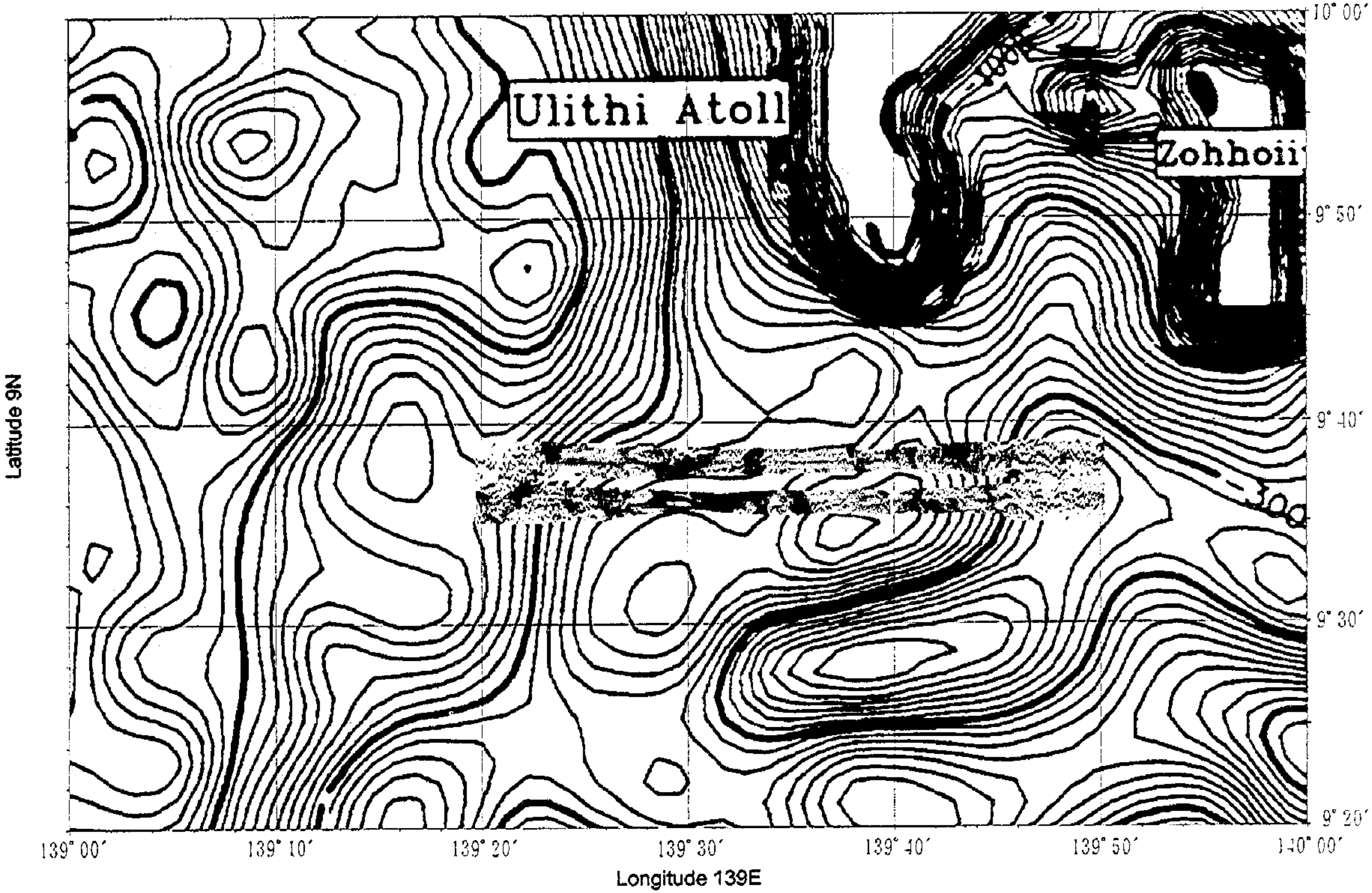

Fig. 3-2-1 (1) Acoustic reflection intensity distribution of MC01 area.

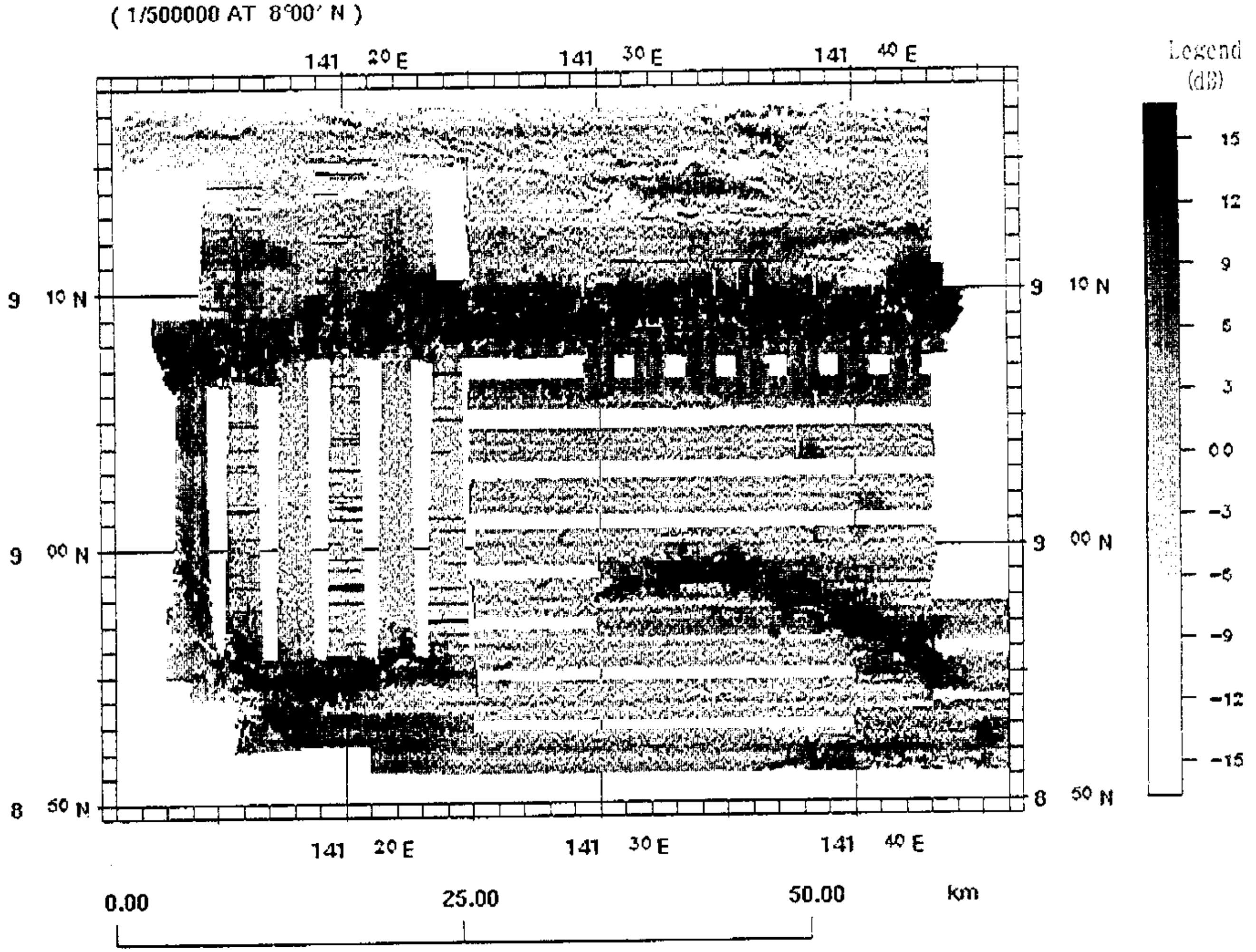

Fig. 3-2-1 (2) Acoustic reflection intensity distribution of MC02 area.

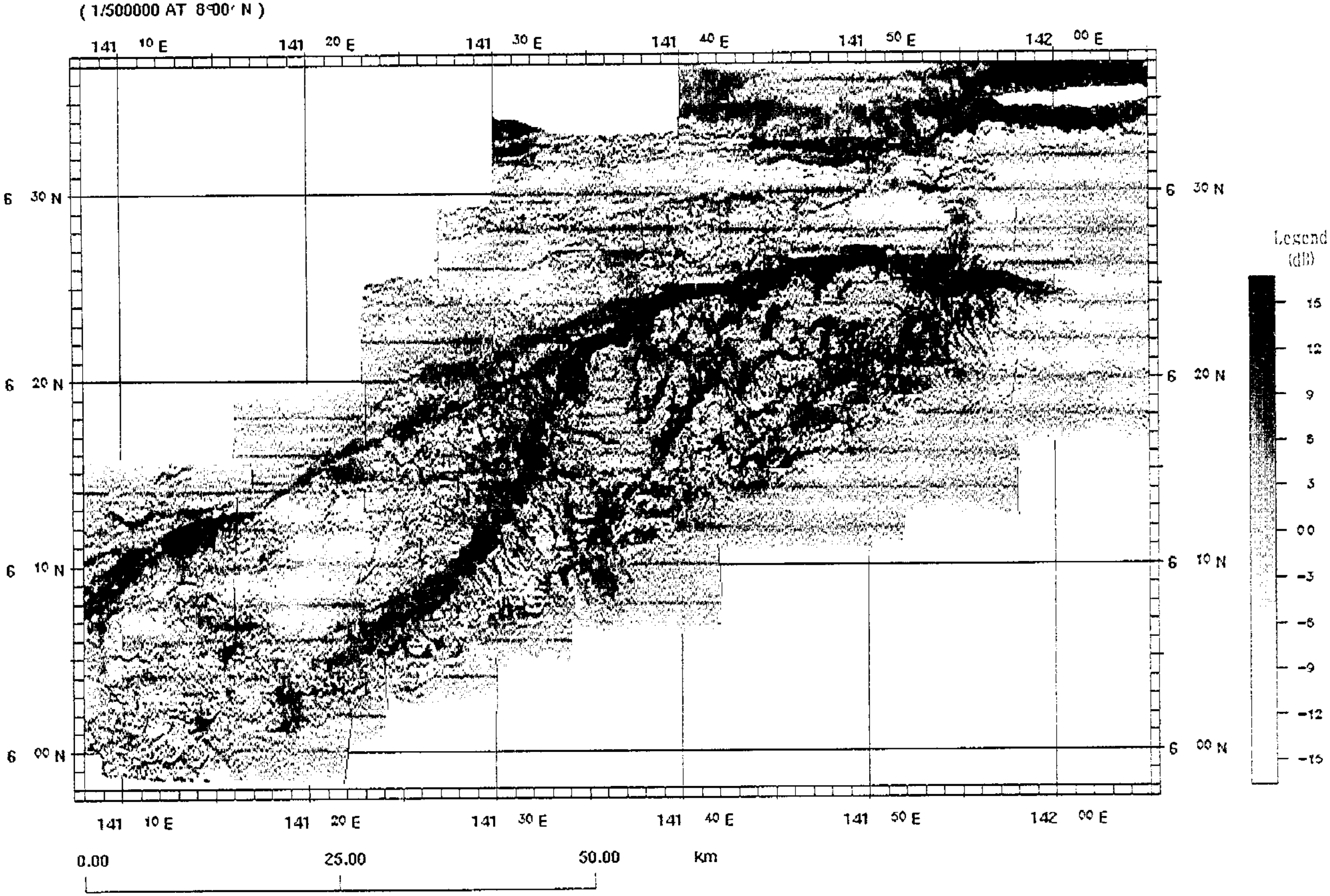

Fig. 3-2-1 (3) Acoustic reflection intensity distribution of MC03 area.

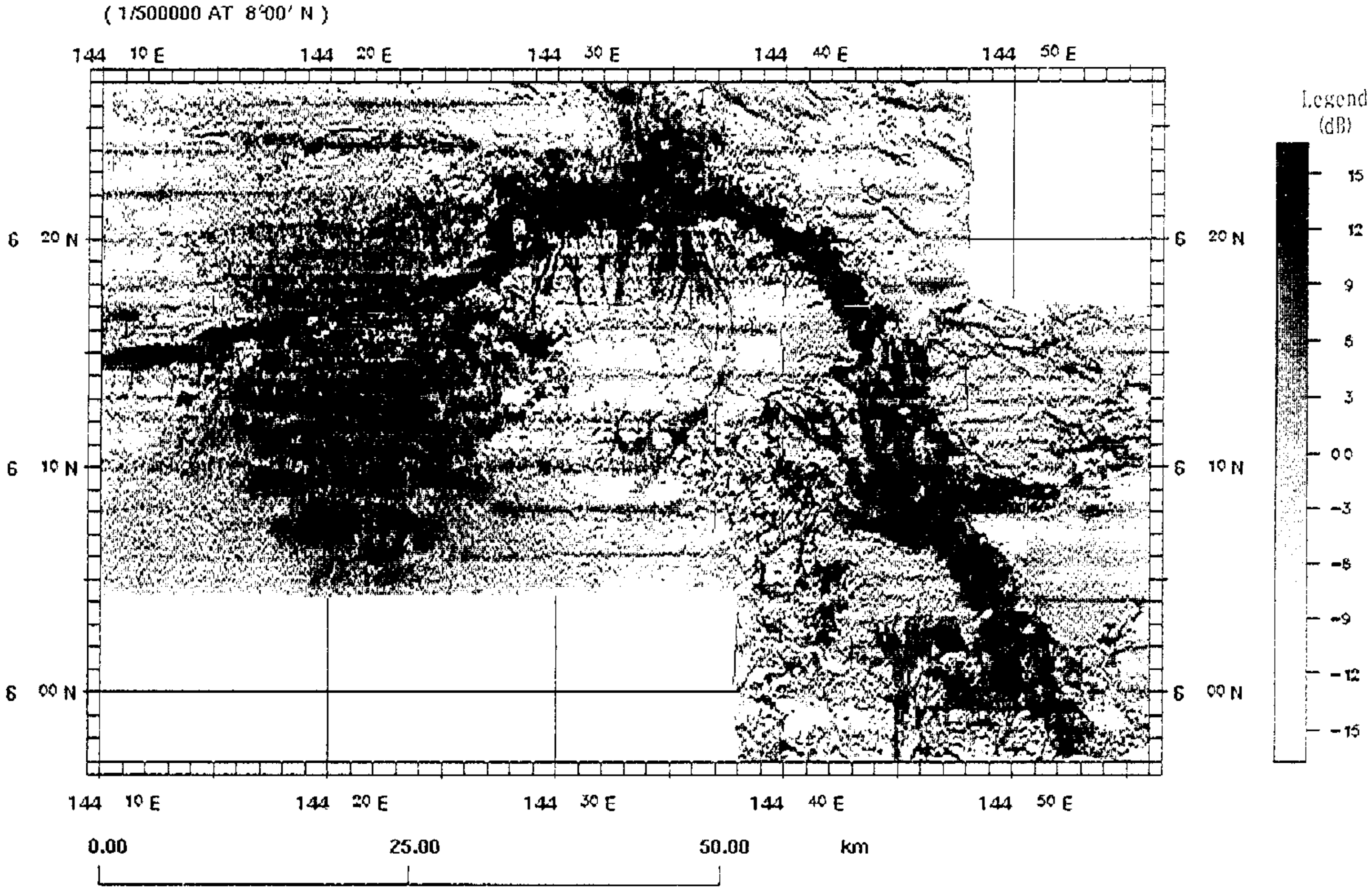

Fig. 3-2-1 (4) Acoustic reflection intensity distribution of MC04 area.

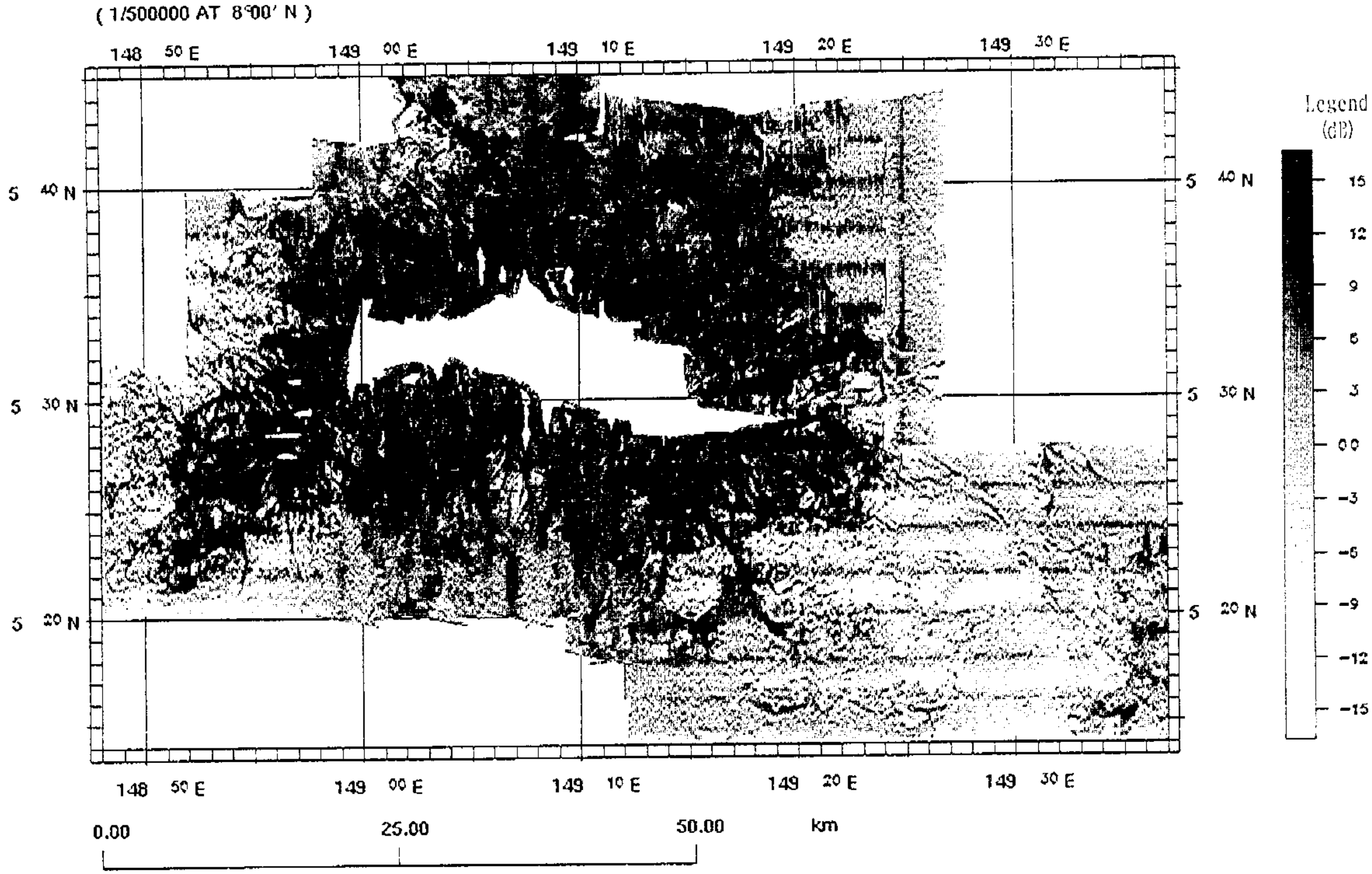

Fig. 3-2-1 (5) Acoustic reflection intensity distribution of MC05 area.

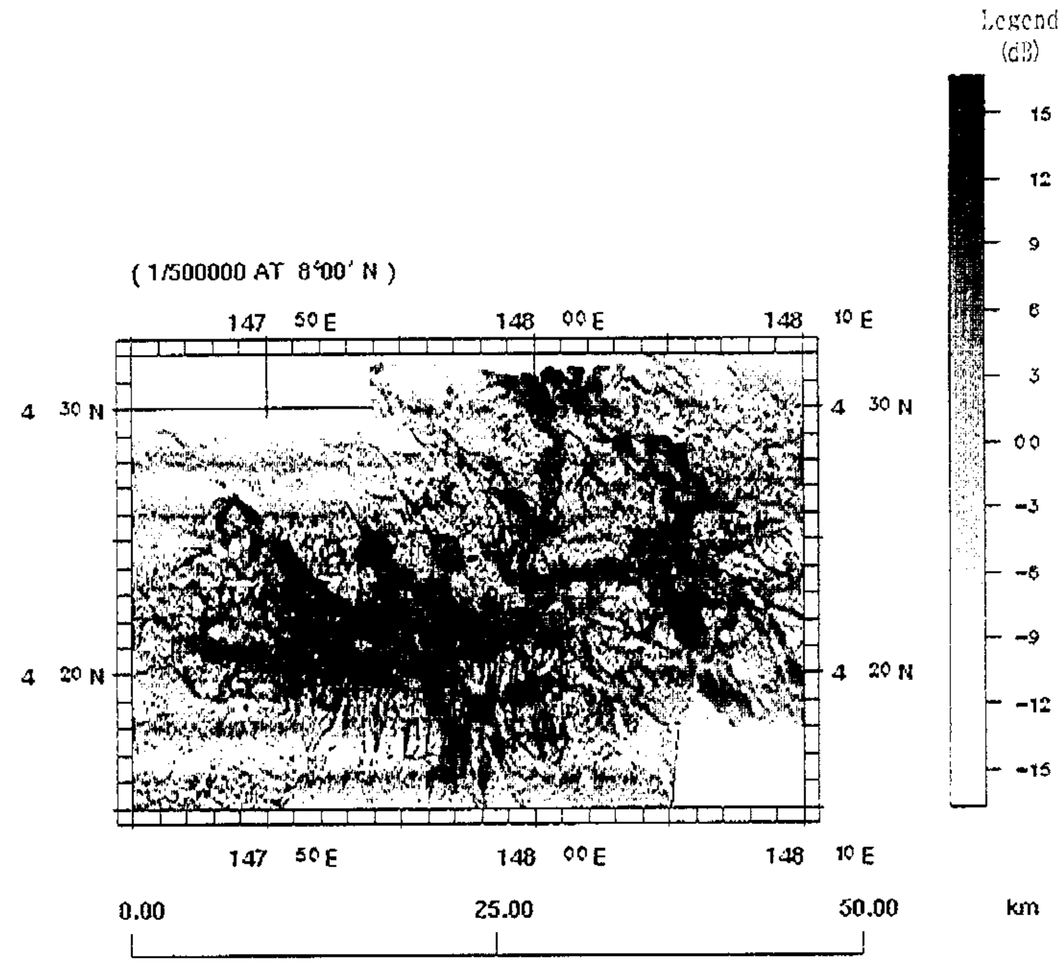

Fig. 3-2-1 (6) Acoustic reflection intensity distribution of MC06 area.

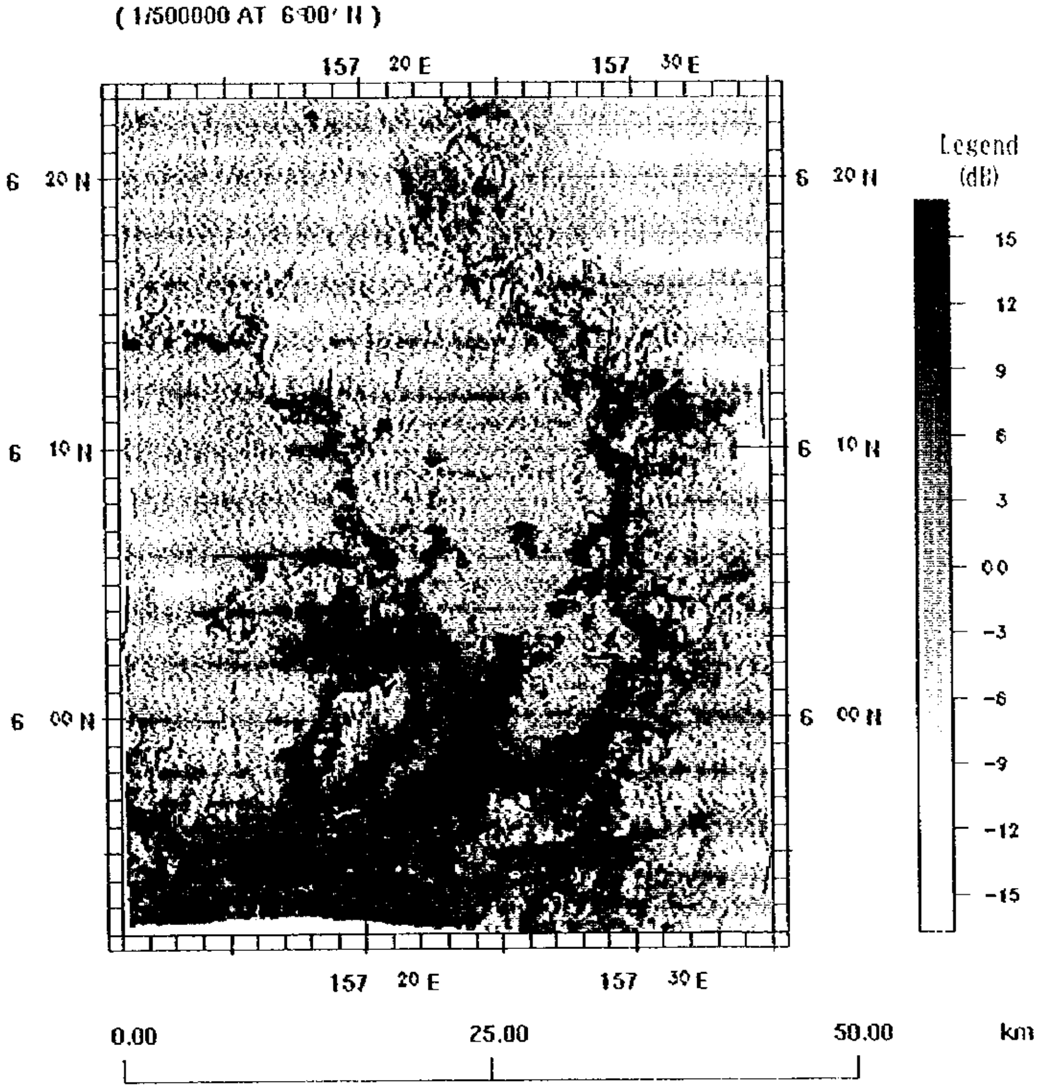

Fig. 3-2-1(7) Acoustic reflection intensity distribution of MC07 area.

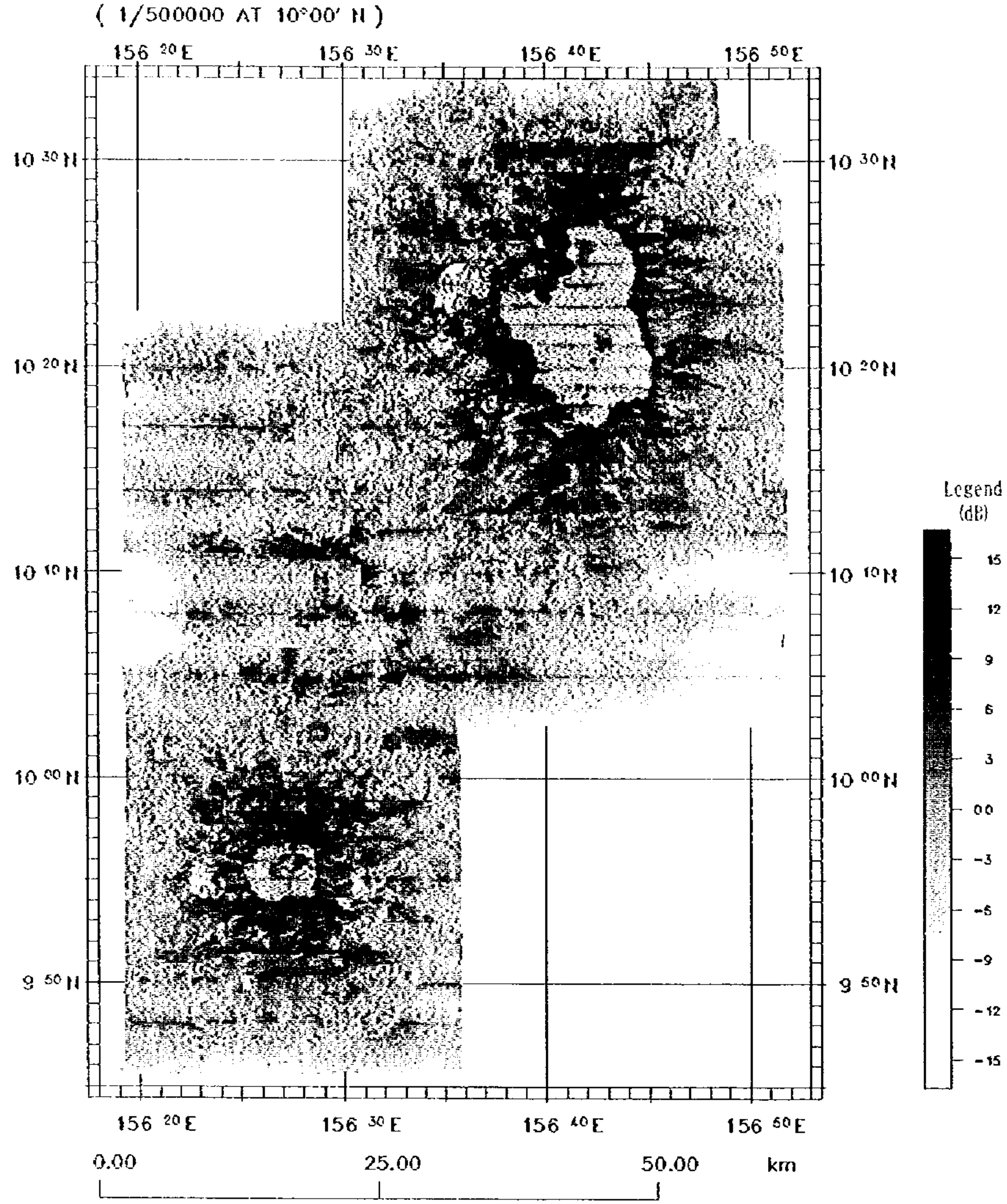

Fig. 3-2-1(8) Acoustic reflection intensity distribution of MC08 area.

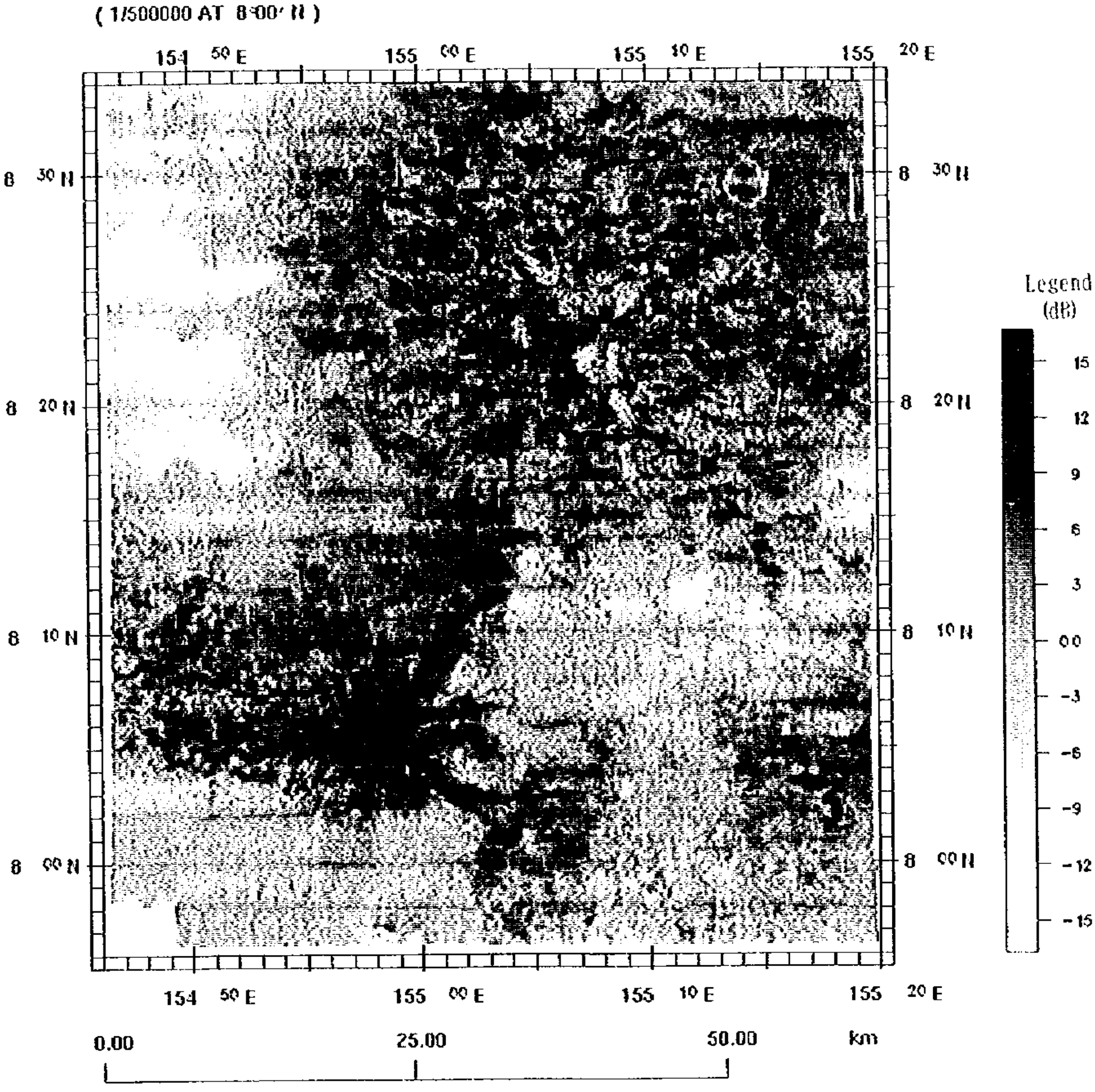

Fig. 3-2-1 (9) Acoustic reflection intensity distribution of MC09 area.

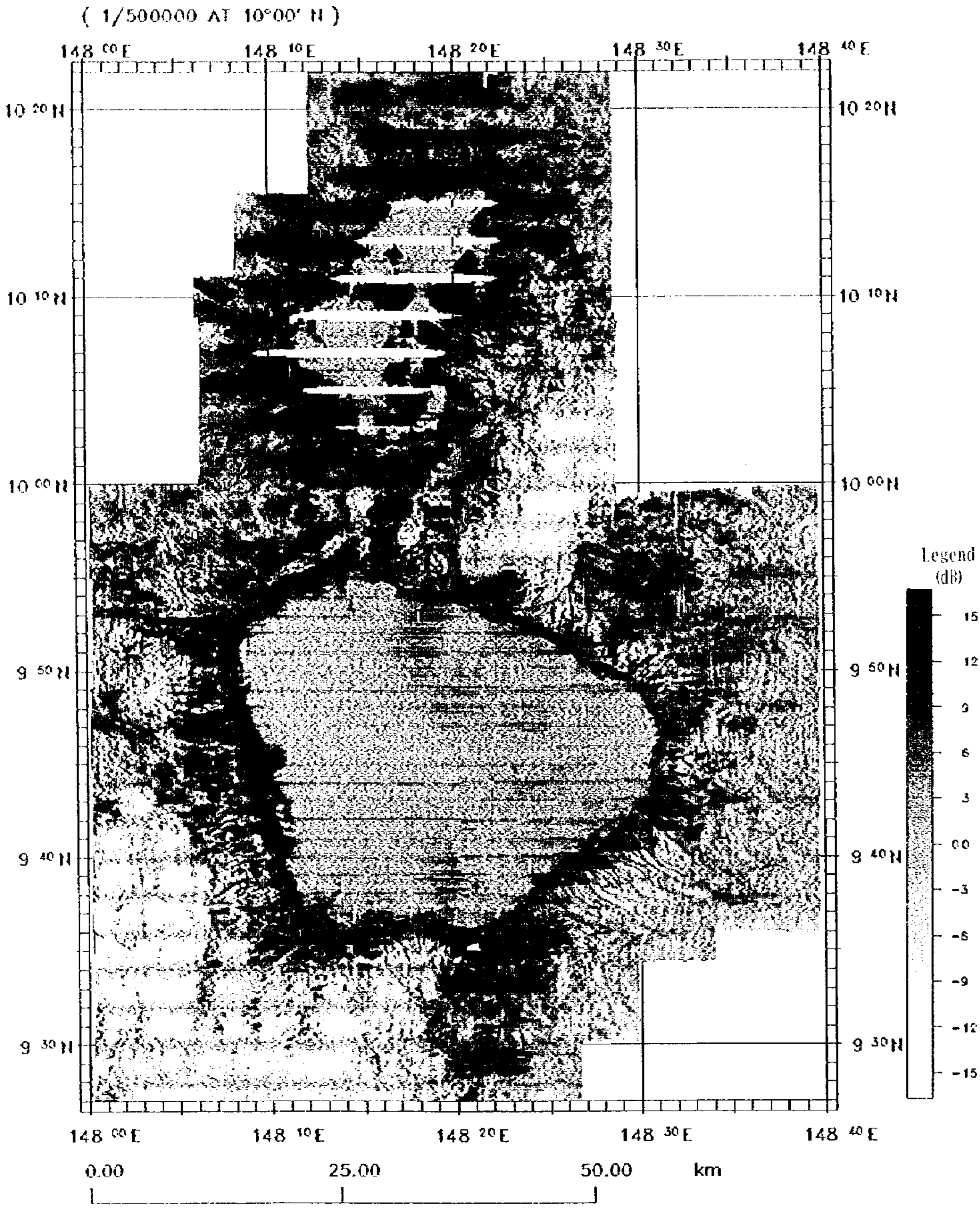

Fig. 3-2-1(10) Acoustic reflection intensity distribution of MC10 area.

In all seamounts, dark colored parts corresponding to exposed rocks occur in the shoulders of the summits, ridges on the slopes, and steep slopes of valleys. On the slopes, the color tone of the map gradually becomes pale downward indicating the increase of unconsolidated sediments toward the lower parts. On the other hand, in parts with low relief such as the flat summit, pale tones corresponding to unconsolidated sediments are generally observed.

In many of the seamounts, the exposed bedrocks are often covered by crusts. Thus the distribution of the exposed bedrocks inferred from the MBES acoustic reflection intensity map indicate possible occurrence of the crusts.

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

1) MC01

The acoustic reflection intensity data of two track lines is shown in Figure 3-2-1 (1). Dark colored parts of the image correspond to the western, eastern, and northern slope of the seamount. Particularly dark parts correspond to steep slopes indicating the exposure of bedrock. On the other hand, pale colored parts are distributed in areas corresponding to the relatively flat parts near the summit and at the foot of the seamount where unconsolidated sediments are believed to be deposited.

2) MC02

Dark color is distributed in parts corresponding to the steep slope in the north indicating the highest reflection acoustic reflection intensity. Most of the summit is covered by pale color showing low reflection acoustic reflection intensity reflecting the coverage of unconsolidated sediments. Dark parts occur in an arc in the southeastern part corresponding to the group of pinnacles indicating exposed bedrocks.

3) MC03

Dark parts are distributed in areas corresponding to the peaks and ridges in the eastern, central, and western parts of the summit indicating exposed bedrocks. The relatively flat parts between the peaks are shown in pale color indicating the wide dominance of unconsolidated sediments. egarding the slopes, the steeper northern slope is shown by darker color compared to the southern slope and it is seen that the shade of the color indicates the acoustic reflection intensity corresponding to the gradient of the slopes.

4) MC04

・ Eastern seamount

On the summit, the dark color is distributed in parts corresponds to the peaks of the NW−SE trending narrow ridge and pinnacles indicating the exposure of the bedrock. Pale color indicating low reflection acoustic reflection intensity occurs in the middle to lower slope with gentle gradient and in flat parts which are covered by unconsolidated sediments. The extremely flat seafloor below 2,900 m depth is shown in pale color indicating low reflection acoustic reflection intensity where the unconsolidated sediment cover is probably thick. The small depressions distributed in the middle to lower slope on the southwestern side is expressed by pale color in indicating the existence of unconsolidated sediments.

・ Western seamount

On the summit, the dark color is distributed in parts corresponding to the peaks of the east−west trending narrow ridge indicating the exposure of bedrock. The terrace type protrusion of the ridge on the southern side of the western part of the summit is characteristically expressed in the image by intermediate shade of color. The dark colored lines extending north−south on the southern slope of the eastern part of the seamount corresponds to valley type topography. Below these linear structure, pale color indicating low reflection acoustic reflection intensity is widely distributed from the lower slope to the foot and base of the seamount showing the wide predominance of unconsolidated sediments.

5) MC05

The shade of the color of the acoustic image is distributed corresponding to the gradient of the summit and the slope. Namely the summit and the upper slope generally are expressed by dark color indicating high reflection acoustic reflection intensity while the color becomes pale downward from the middle to the lower slope. The lowest reflection acoustic reflection intensity is shown at the lower southeastern slope below the terrace type protrusion showing the predominance of unconsolidated sediments. The lower parts of the southern and northern slope characteristically show intermediate shade of color in the image. The NW−SE linear structure extending from the lower northeastern slope to the foot of the seamount is expressed in dark color indicating the exposure of bedrock.

6) MC06

Dark color is distributed at the three peaks and their vicinity on the summit indicating the highest reflection acoustic reflection intensity, bedrocks are believed to be widely exposed here. Regarding the slopes, on the whole, the dark colors correspond to the steep parts and the pale colors to the gentle parts. Particularly the steep southern and northeastern slopes are expressed by dark tone indicating exposed bedrock. Also fine variation of the color tone is observed in the slope areas corresponding to the minor topographic relief. The many dark lines on the southern side of the seamount correspond to the valley topography.

7) MC07

Pale image color is widely distributed in the central part of the summit indicating low reflection acoustic reflection intensity showing the predominance of unconsolidated sediments. This low acoustic reflection intensity zone continues to the northern seamount. The saddle between MC07 and the northern seamount seems to have low acoustic reflection intensity and the image show paler color than the summit.

Dark color is particularly noted in areas corresponding to the many pinnacles in the central part of the summit and along the summit periphery where the bedrock is exposed. However, the dark part in the eastern shoulder is in the somewhat gentle gradient area shallower than 2,500 m while in the western shoulder the dark color appears in the transitional area to the slope deeper than 2,500 m. Also there are many pinnacles at the contact with the southern seamount and the relief is rugged and here the color is dark indicating the lack of unconsolidated sediments.

The areas corresponding to the caldera type depression in the western side of the seamount and the eastern base are expressed in pale color indicating the existence of unconsolidated sediments.

8) MC08

Pale color image showing low reflection acoustic reflection intensity is widely observed in the central part of the summit reflecting the occurrence of unconsolidated sediments. In the areas of pinnacles on the flat summit, however, dark color tone of the high acoustic reflection intensity is observed showing the exposure of bedrock. In the northern part of the summit, somewhat dark tone of color occurs indicating medium acoustic reflection intensity and this is inferred to reflect the occurrence of nodule form material.

Dark color is distributed from the shoulder of the summit periphery to the upper slope indicating the highest reflection acoustic reflection intensity. The color gradually fades from the middle to the lower slope indicating the gradual increase of unconsolidated sediments. Also variation of color tone corresponding to the ridges and creeks are observed on the slopes.

The color distribution of the small seamount to the south of MC08 is similar, but here, the bedrock is exposed at the shallowest part of the summit.

9) MC09

- Northern seamount

The summit has a very rugged relief with many pinnacles and the seafloor topography is very complex. Thus the acoustic reflection intensity is very complex reflecting the topography. Namely dark color reflecting bedrock exposure is distributed throughout the summit, but pale zones occur locally showing that the depressions are covered by unconsolidated sediments. Also unlike most other seamounts, dark color tone indicating high acoustic reflection intensity is not observed at the periphery of the summit and the shoulder and the upper slope cannot be distinguished.

Dark and pale color tones are generally distributed alternately corresponding to the ridges and creeks on the slopes.

- Southern seamount

This is a pointed seamount without flat summit and unconsolidated sediments are not observed from acoustic image. Dark color indicating exposed bedrock is distributed throughout the seamount with the exception of some creeks. But the oceanic plateau below 3,900 m depth on the southern side of the seamount is extremely flat and is most probably covered by unconsolidated sediments.

10) MC10

This is a typical table top seamount and the central part of the summit is widely covered by unconsolidated sediments forming a dome without relief. The acoustic reflection intensity of the central part of the summit is not constant and considerable area is covered by somewhat dark tone suggesting the occurrence of nodules. The zone corresponding to the shoulder at the periphery of the summit is shown by dark color and indicating the highest acoustic reflection intensity. There is also a relatively dark part from the shoulder to the upper slope indicating high acoustic reflection next to the shoulder showing the ridge to consist of exposed bedrock. The color gradually fades from the middle slope downward in relation to the decrease in gradient and increase of unconsolidated sediments. Also