3 - 3 SBP Survey

(1) SBP analysis

SBP survey was carried out in order to clarify the distribution of the sediments under the seafloor. Although nSBP used has high record resolution, it is not possible to obtain reflection from seafloor with more than 5° inclination. Therefore the survey was carried out from the summit to parts of the upper slope and the piedmont of the seamounts.

The lowermost reflection on the record was used as the acoustic basement, and the total thickness of the alternation of the acoustically transparent (blank parts on the monitor images) and opaque (colored parts on the monitor images) layers was read from the record as corresponding to the thickness of the unconsolidated sediments. And the results were expressed as isopach map of each seamount. The acoustic basement sometimes include not only the bedrock, but also the dense parts of the unconsolidated sediments and those zones including many pebbles. Thus the unconsolidated sediments are often thicker than that indicated on the SBP records. The SBP sediment layers in this paper indicate the thickness from the seafloor to the acoustic basement.

The results of the SBP survey match the summit topography and show thick sediments in the central parts of dome-shaped guyots in areas MS10, MS11, and MS12. In these seamounts, there are localities in the peripheral parts of the summit where bedrocks are exposed with very little sediments. The MBES acoustic reflection intensity gradually decreases from the upper slope downward indicating the tendency of sediment thickening, but it is difficult to confirm such tendency from the SBP records.

The seamount in area MS13 is totally covered by thick sediments with the exception of the summit. Spots inferred to be outcrops are scattered on the summit indicating many pinnacles and thin sediments are recognized in the depressions in-between.

(2) Classification of SBP types

The reflection patterns of the SBP record of the four areas were classified into O-type and T-type as shown in Figure 3-3-1.

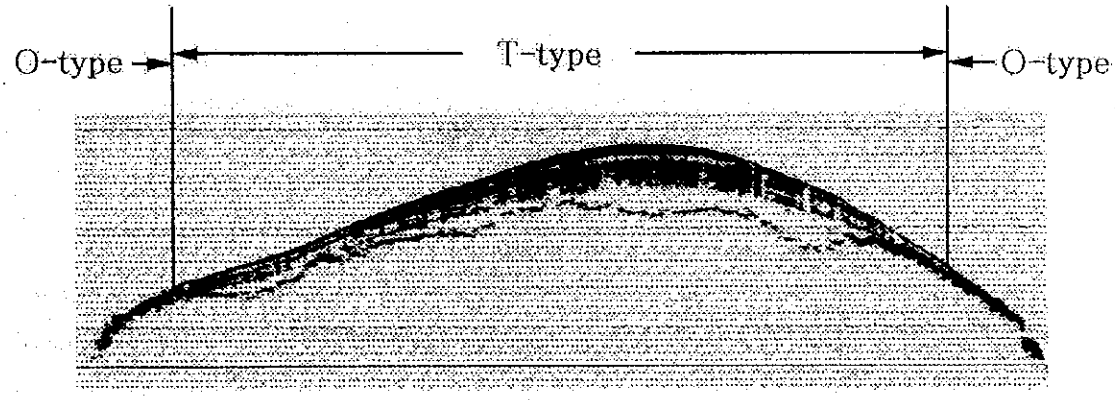


Fig. 3-3-1 Types of nSBP Record

1) O-type

The SBP reflection patterns consist entirely of acoustically opaque layers.

O-type is observed in the whole seamount of pointed seamounts. It is seen from the summit peripheries to the slopes of the guyots. This type generally corresponds to rock outcrops or manganese crusts and at times to those thinly covered by sediments.

2) T-type

The SBP reflection patterns consist of alternation of acoustically transparent and opaque layers.

T-type reflection appears at guyot summits and terraces. The thickness of the alternation varies considerably from 10 to 100m. This type is considered to correspond to unconsolidated sediments.

(3) Characteristic features of individual areas

1) MS10 area

The SBP section and an isopach map of the summit are laid out in Figure 3-3-2(1) and 3-3-3(1).

The central part of the summit is covered by unconsolidated sediments. These sediments are generally 40m thick, thickening towards the peak from the periphery and the maximum thickness is over 50m. There are pinnacles along 12° 19' N on the summit and sediments are not observed in the vicinity.

Sediments are hardly observed on the upper to middle slope and it is believed that bedrocks are exposed widely on the slope.

2) MS11 area

The SBP section and an isopach map of the summit are laid out in Figure 3-3-2(2) and 3-3-3(2).

The whole summit is covered by unconsolidated sediments. It is inferred that sediments are over100m at the thickest part, although it is not clear on the record. The sediments generally thickens to the south, and the thickness exceeds 90m to the south of 10° 50' N. There are pinnacles on the summit the sediments are thin in the vicinity. Thus the isopach contour is irregular in these parts.

Exposed bedrocks are observed along the shoulder of the summit. Also sediments are hardly observed on the upper slope, and there probably is a wide occurrence of exposed bedrocks.

3) MS12 area

The SBP section and an isopach map of the summit are laid out in Figure 3-3-2(3) and 3-3-3(3).

With the exception of the pinnacles along the 8° 45' N and the protrusion to the north and south on the western side of the seamount, the central part of the summit is wholly covered by unconsolidated

sediments. The sediments thicken towards the peak from the shoulder with a maximum exceeding 120m.

On the peripheral part of the summit, sediments are observed to the shoulder on the eastern and southern sides; but the western and northern side consist of exposed bedrocks.

The sediments on the slope is generally thin, particularly the bedrocks are inferred to be exposed to the middle slope on the northern and western slopes.

4) MS13 area

The SBP section and an isopach map of the summit are laid out in Figure 3-3-2(4) and 3-3-3(4).

The central part of the summit has large relief with many pinnacles. Acoustic basement rocks occur scattered on the summit and it is believed to correspond to the pinnacles. The northern summit has gentle undulating surface and unconsolidated sediment expressed by acoustically transparent layers are distributed with thickness locally exceeding 80m.

3 - 4 SSS Survey

SSS survey was carried out with the major objective of clarifying the micro- topography of exposed bedrocks and the distribution of cobbles. Thus the track lines were set through the exposed bedrocks in the summit periphery, particularly the terraces.

The results show that, with the exception of the MS13 area, the seamounts of the study area have narrow terrace-like topography at the periphery of the summits and that the occurrence of cobble crusts is possible in these parts.

The results of the SSS survey in various areas are reported below.

1) MS10 area

The position of the SSS track line and image of MS10 area are shown in Figure 3-4-1 (1).

The SSS track line extends approximately 5nm at the southern periphery of the summit in order to clarify the distribution of the pebbly material and the exposed bedrock at the periphery. At the eastern and western end of the track line, terrace-like topography is observed at localities lower than the flat part of the dome summit. Strong reflection indicating the existence of pebbly material is observed evenly on these terraces. Cobble crust was collected near the western end of the track line and this supports the above view.

2) MS11 area

The position of the SSS track line and image of MS11 area is shown in Figure 3-4-1 (2).

MS11 seamount is a large guyot. High dome with relative height of 700m from the shoulder to the peak occur on the summit, and ridge-type protrusion form a small hill at the summit periphery. The small hill is prominent by SSS survey, and approximately 7nm long track line was set on the steep southeastern slope in order to confirm the distribution of the unconsolidated sediments and the cobbles.

The result of the survey show that the periphery is generally pale in color and is covered by unconsolidated sediments to the shoulder. On the other hand, dark color is observed evenly on the terrace below the small hill indicating the existence of cobbles.

3) MS12 area

The position of the SSS track line and image of MS12 area are shown in Figure 3-4-1 (3).

MS12 seamount is believed to be structurally controlled in the southwest-northeast direction from planar topography. The wide terrace which extends southeastward from the pinnacles in the central part of the summit is particularly characteristic. On this seamount, 7nm SSS survey track line was set from the western end of this terrace through the base of the protrusion to the southern periphery of the summit with the objective of clarifying the development of the terrace and the distribution of the cobbles.

The results show that unconsolidated sediments are distributed in dome shape at the northern side of the central summit, and the terrace occurs immediately below the track line on the southern side. The protrusion at the southwestern end is the extension of this terrace and bedrock outcrops occur in the relatively steep part, unconsolidated sediments on the gently sloping part, and cobbles occur in the intermediate part.

4) MS13 area

The position of the SSS track line and image of MS13 area are shown in Figure 3-4-1 (4).

As the unconsolidated sediment cover is small in this seamount, SSS survey was conducted with the purpose of confirming the distribution of the cobbles and unconsolidated sediments in the depressions. There are two lines of bedrock exposures, either pinnacles or ridge topography, in the central part of the summit and thus the approximately 5nm track line was set across the exposure. Here, it is believed that almost throughout the track line bedrocks are exposed and dark color tone prevails with the exception of the pale-colored zone between 160° 36'~160° 37' E, and the northern side of 160° 37'~160° 38' E. Dark color tone is widely observed even in the depressions between the pinnacles, and it is considered that the occurrence of unconsolidated sediments are local.

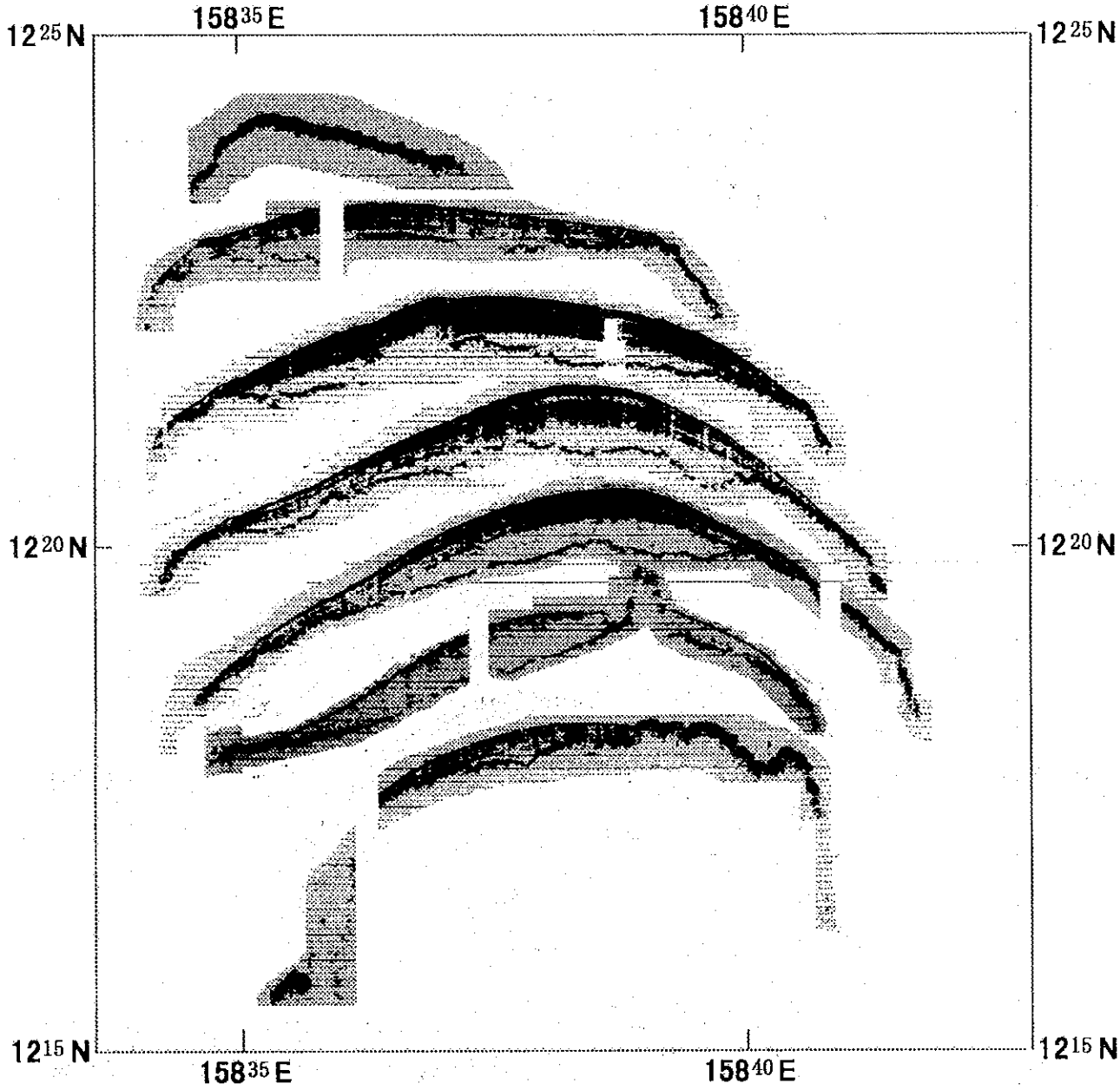


Fig. 3－3－2 (1) SBP Profiles of MS10 Area

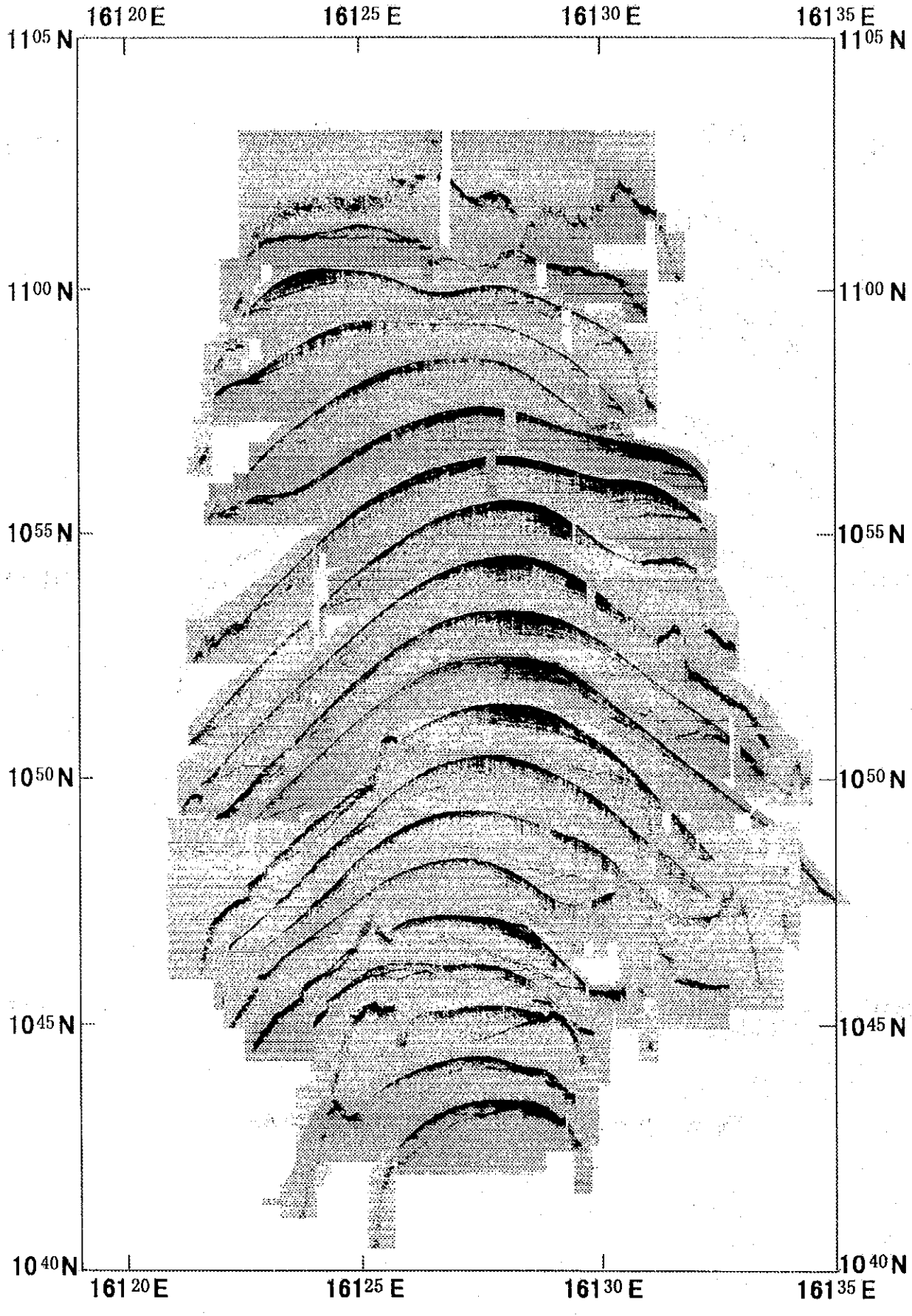


Fig. 3－3－2 (2) SBP Profiles of MS11 Area

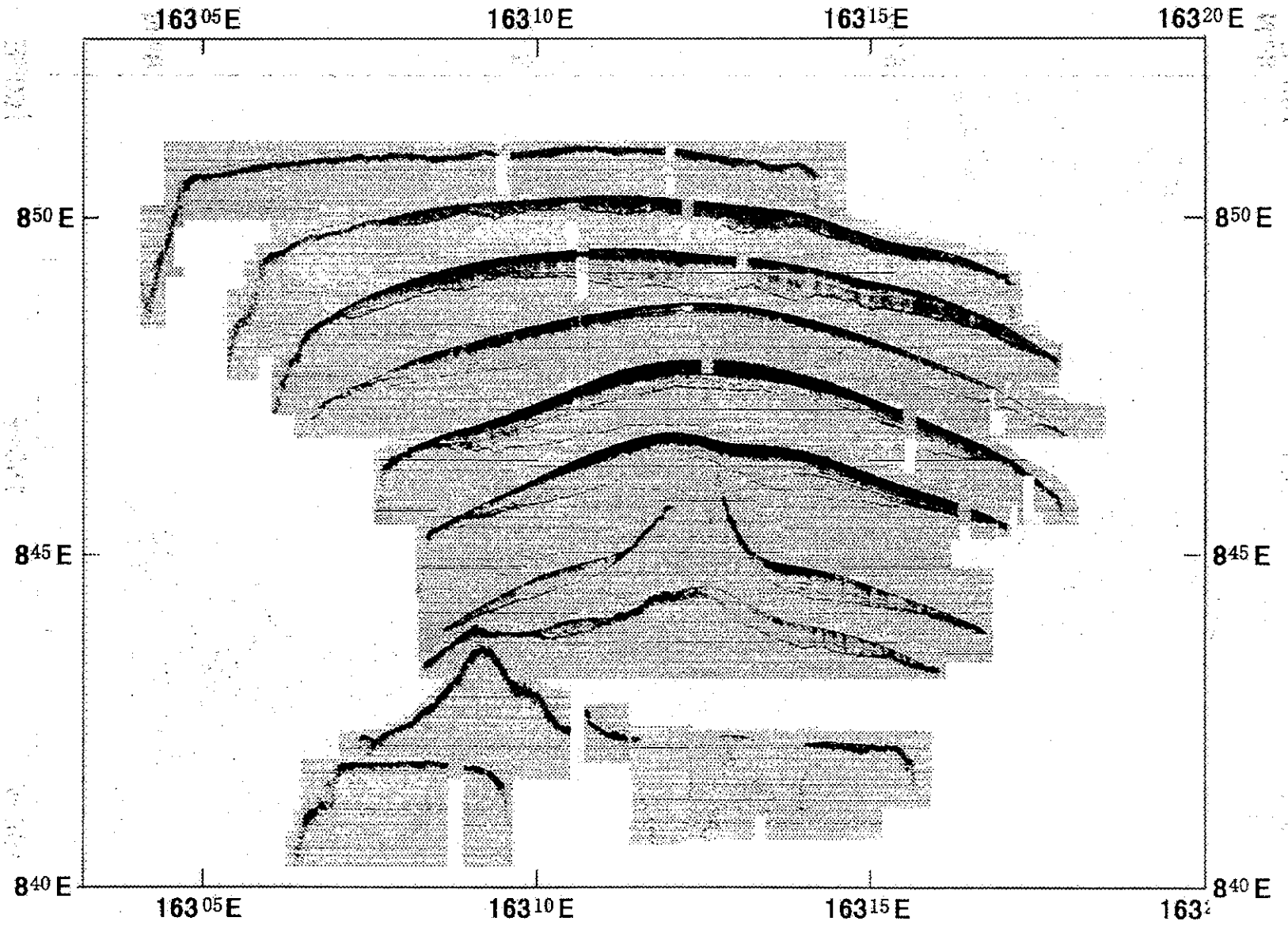


Fig. 3－3－2 (3) SBP Profiles of MS12 Area

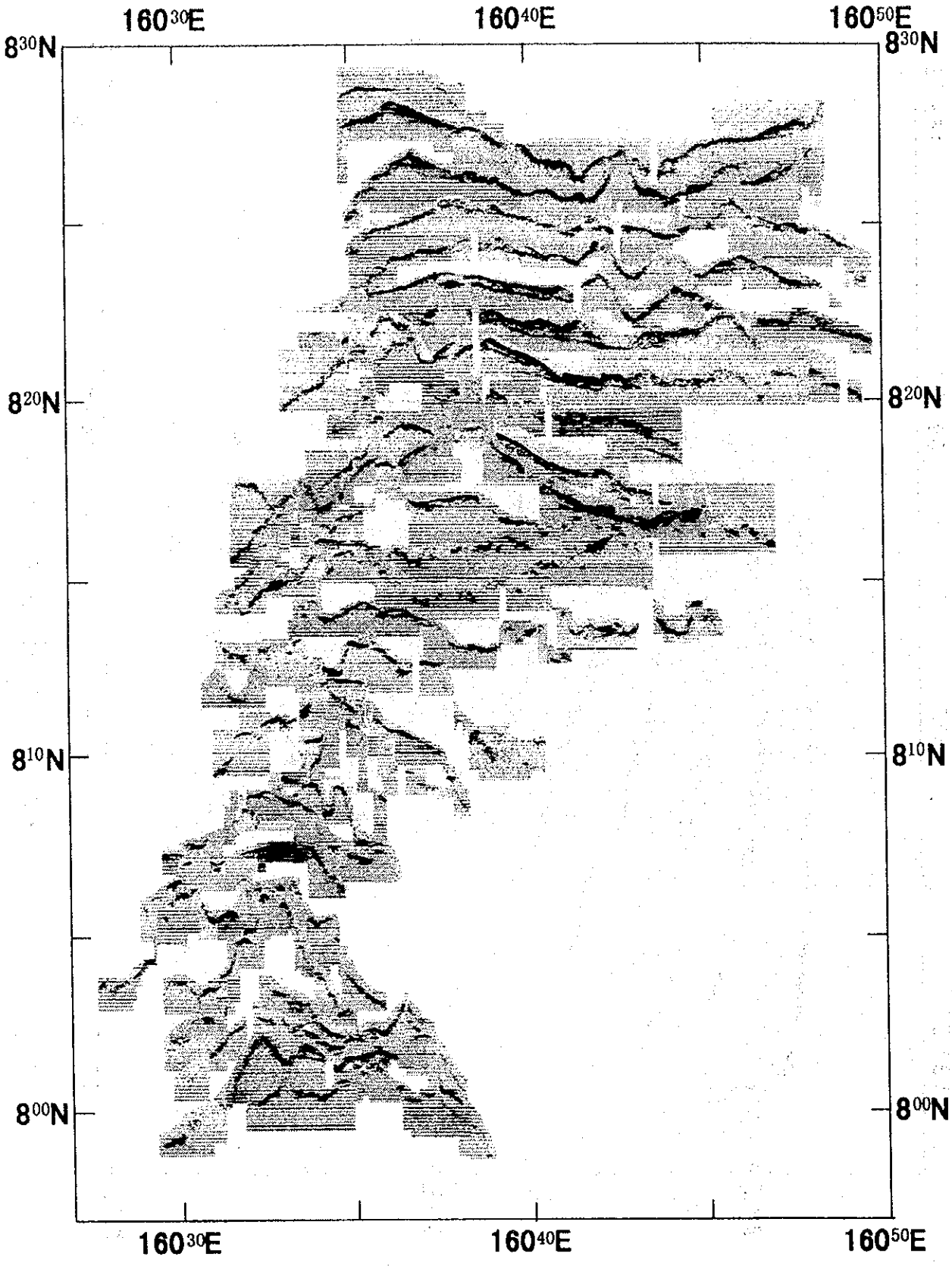


Fig. 3－3－2 （4） SBP Profiles of MS13 Area

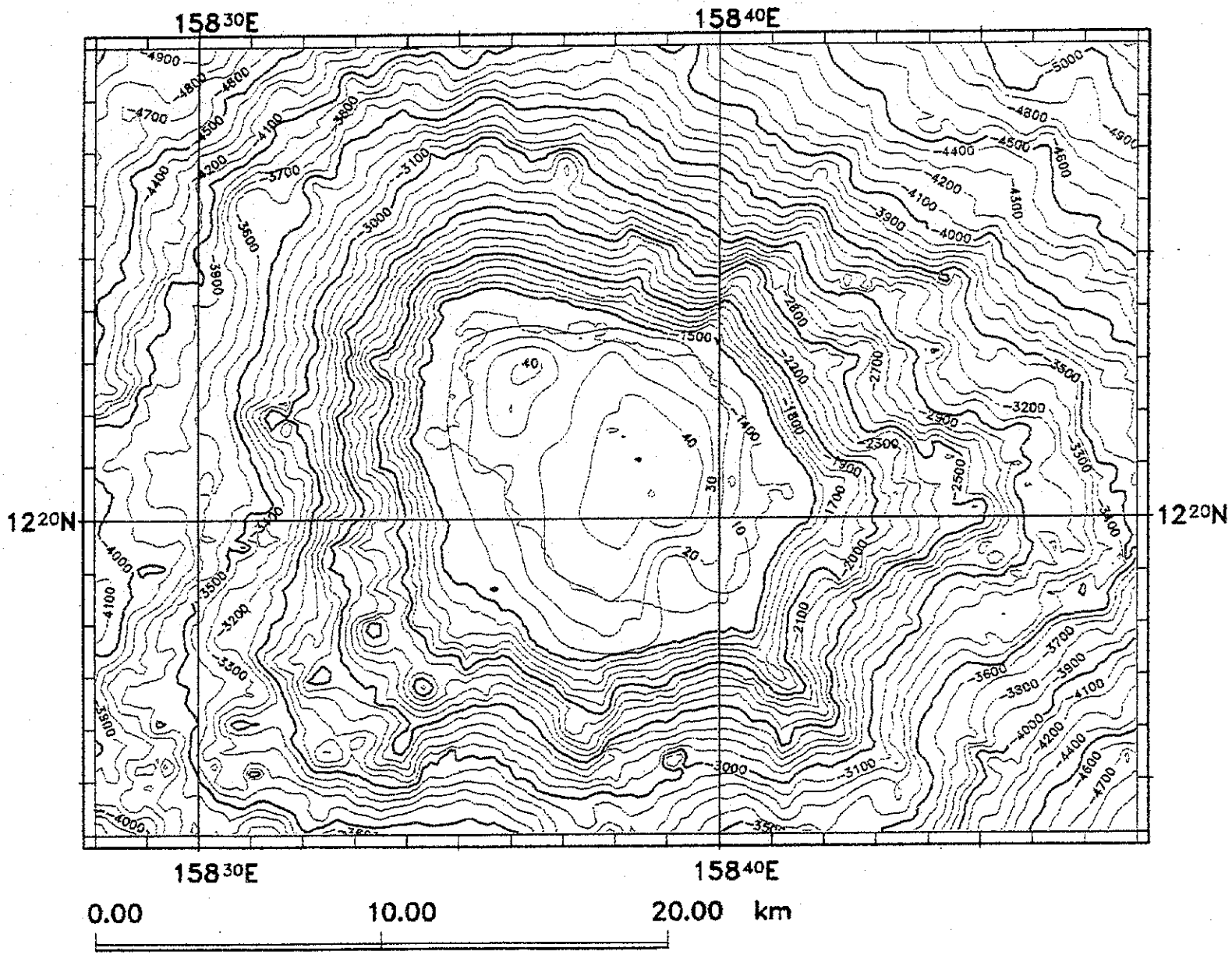


Fig.3-3-3(1) Isopach map of MS10 area.

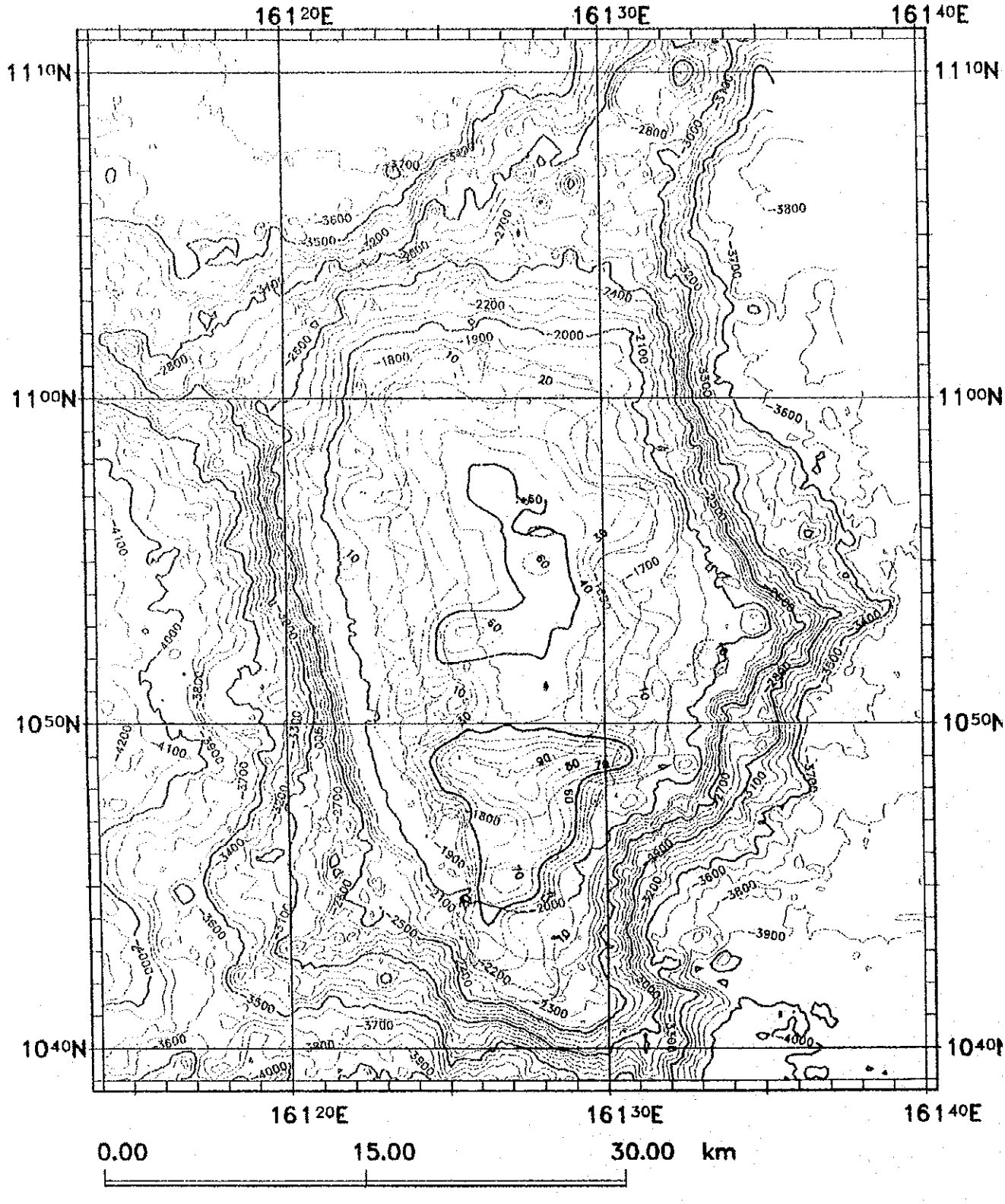


Fig.3-3-3(2) Isopach map of MS11 area.

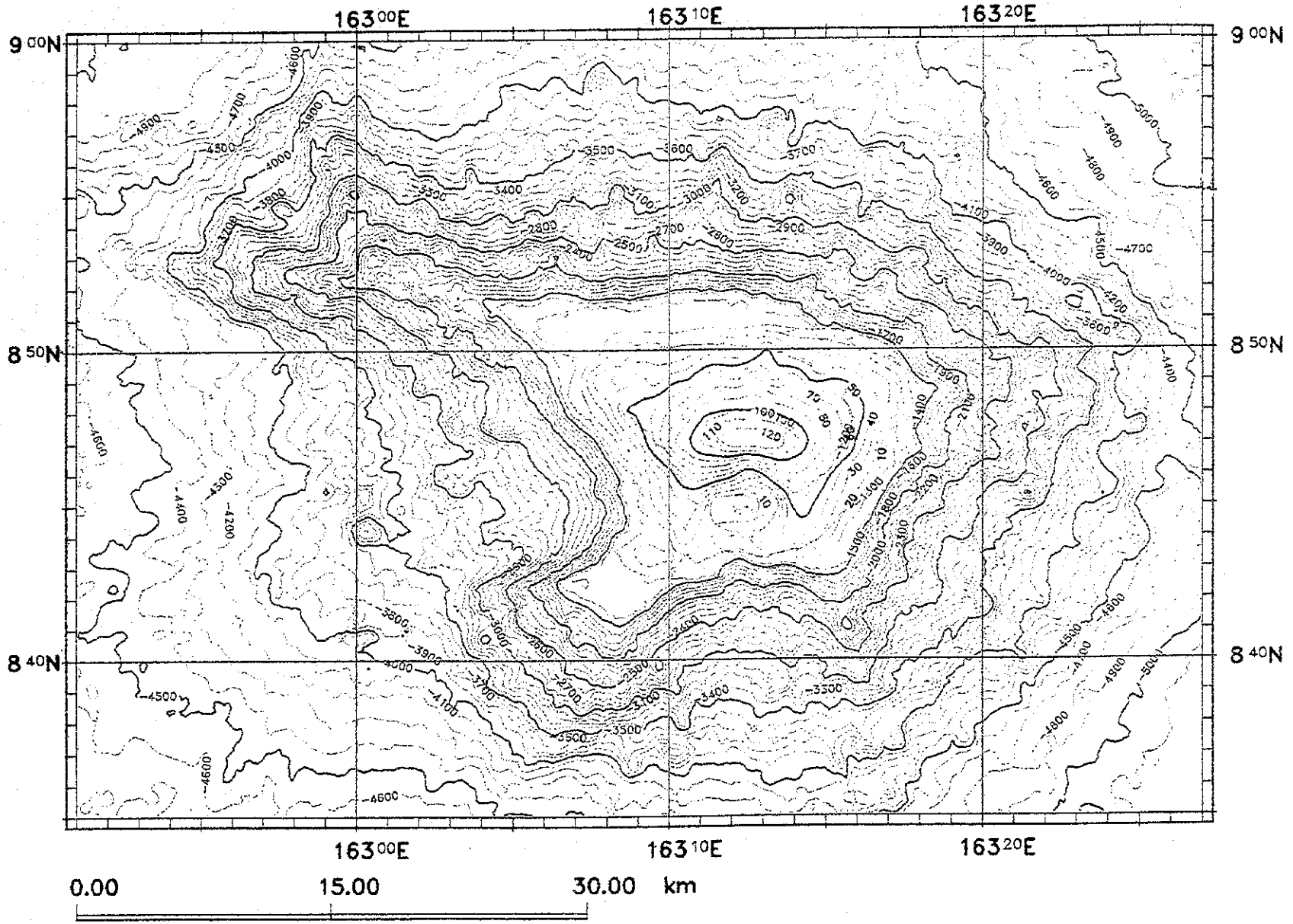


Fig.3-3-3(3) Isopach map of MS12 area.

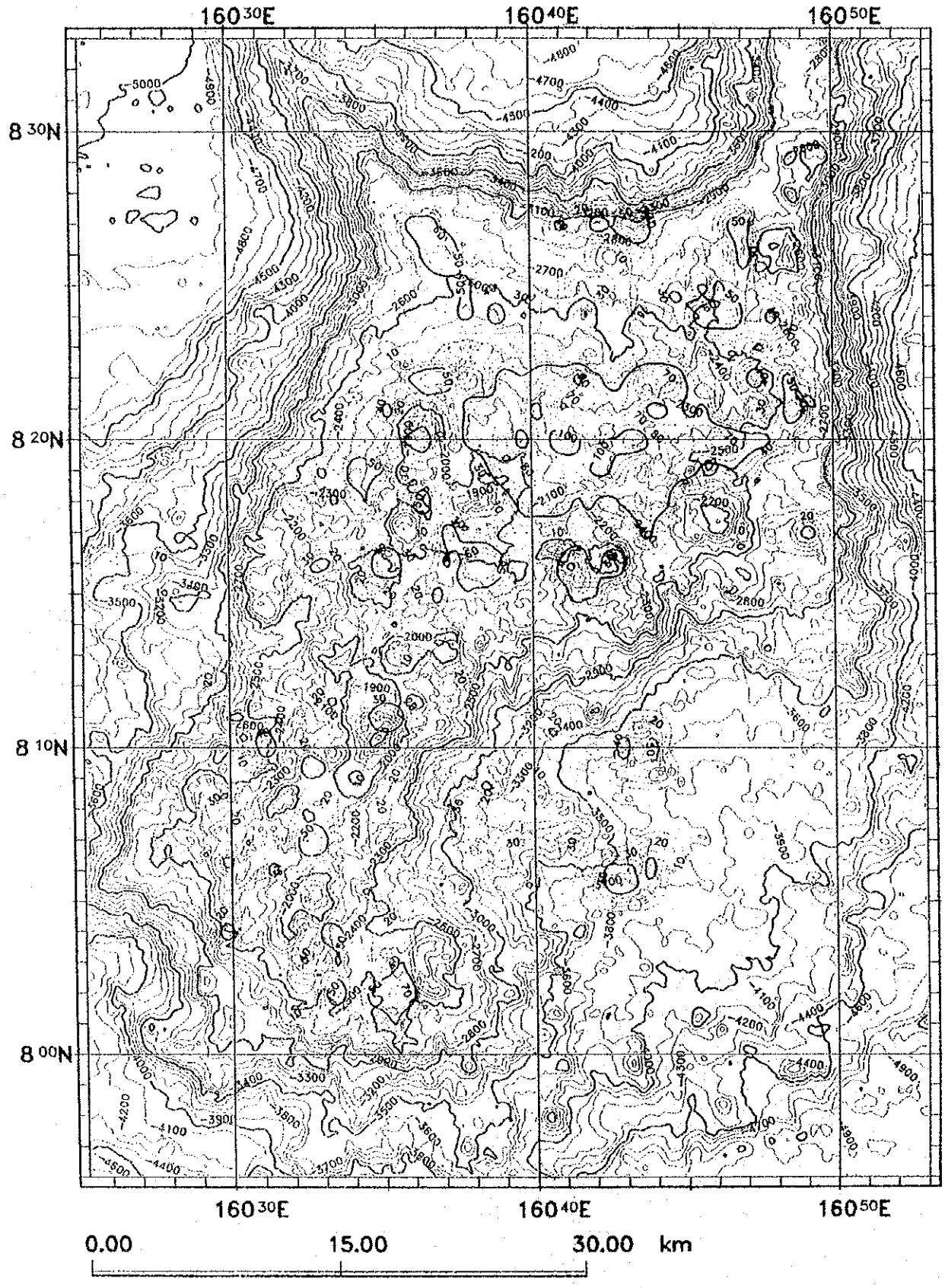
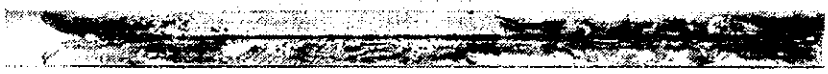
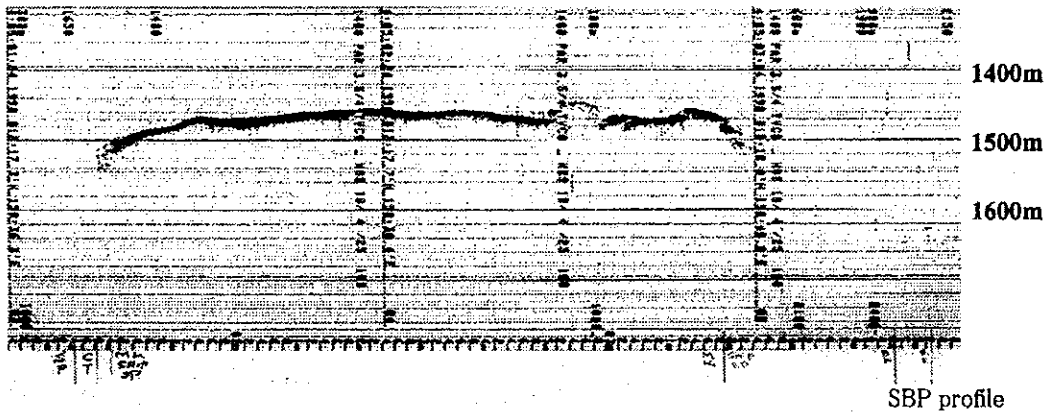


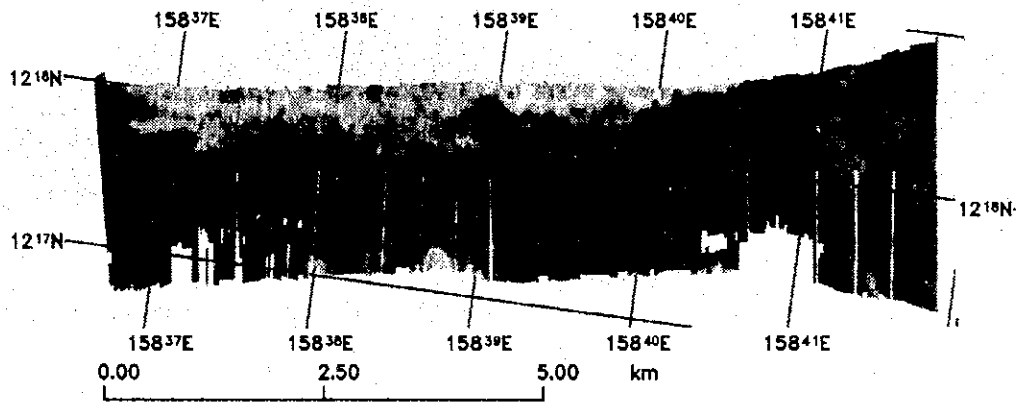
Fig.3-3-3(4) Isopach map of MS13 area.



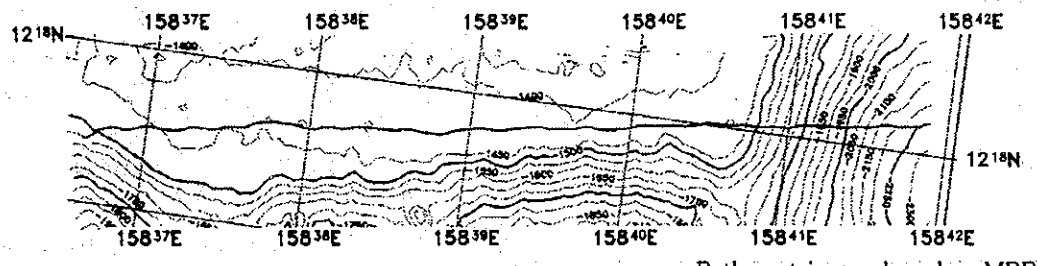
Sidescan Image



SBP profile

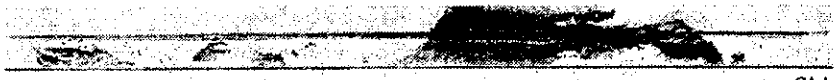


Acoustic reflection image based on MBES

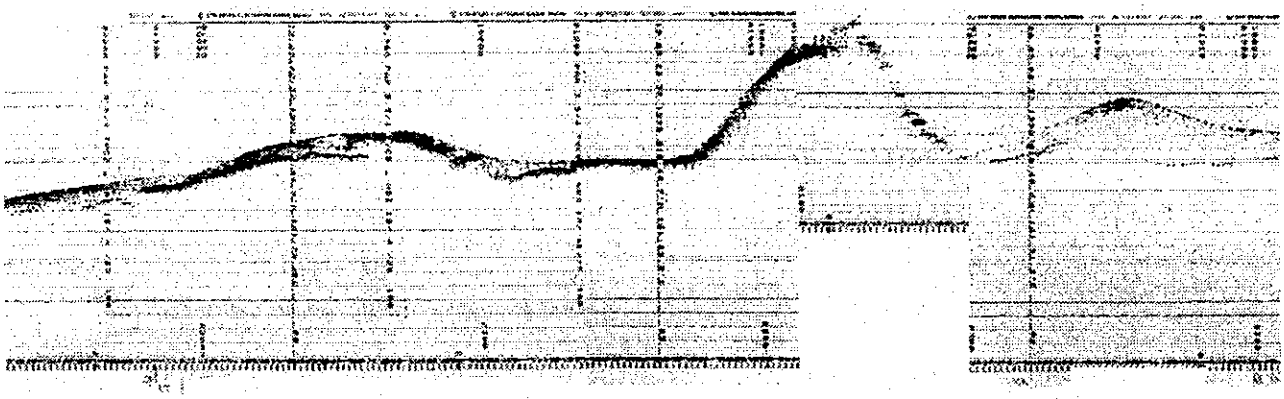


Bathymetric map based on MBES

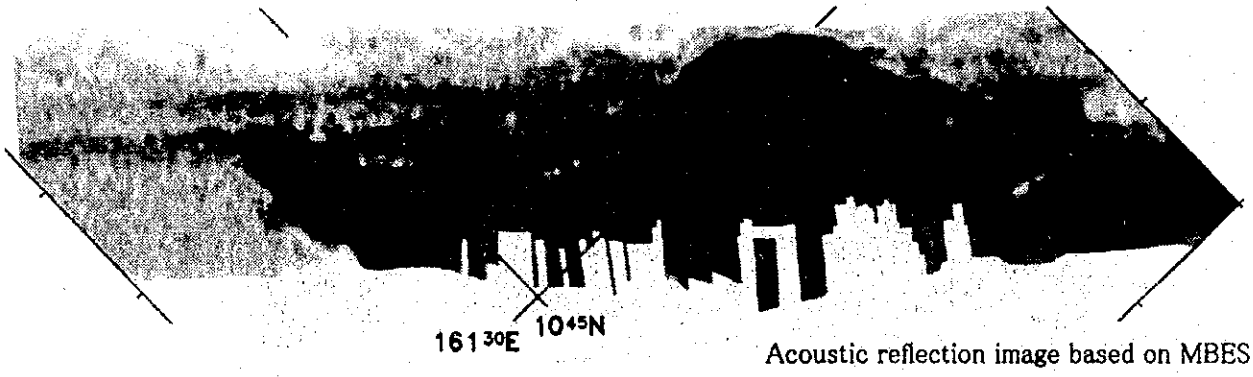
Fig. 3-4-1(1) Results of side scan sonar survey of MS10 area



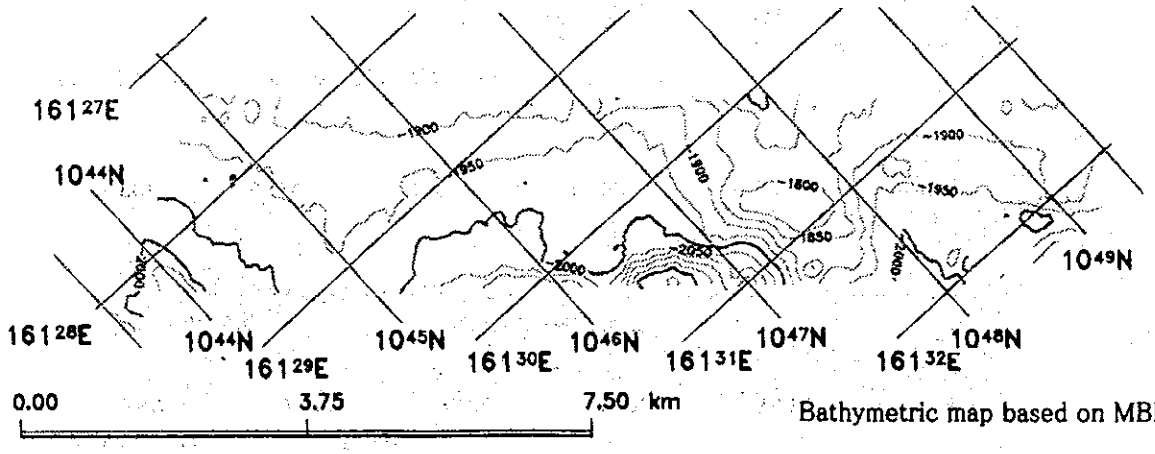
Sidescan Image



SBP profile

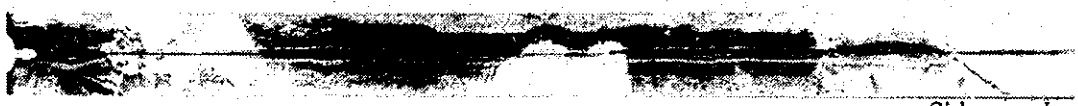


Acoustic reflection image based on MBES

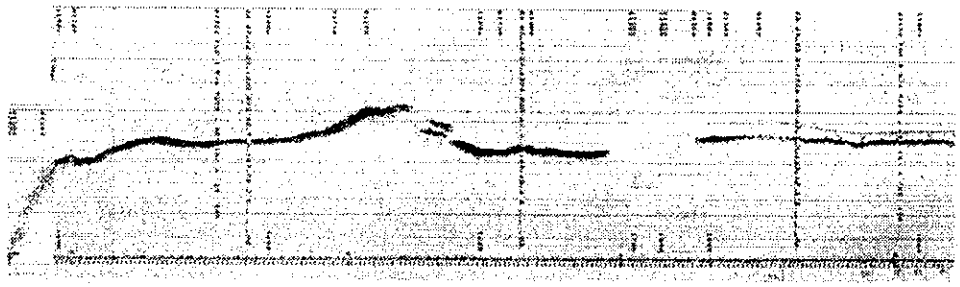


Bathymetric map based on MBES

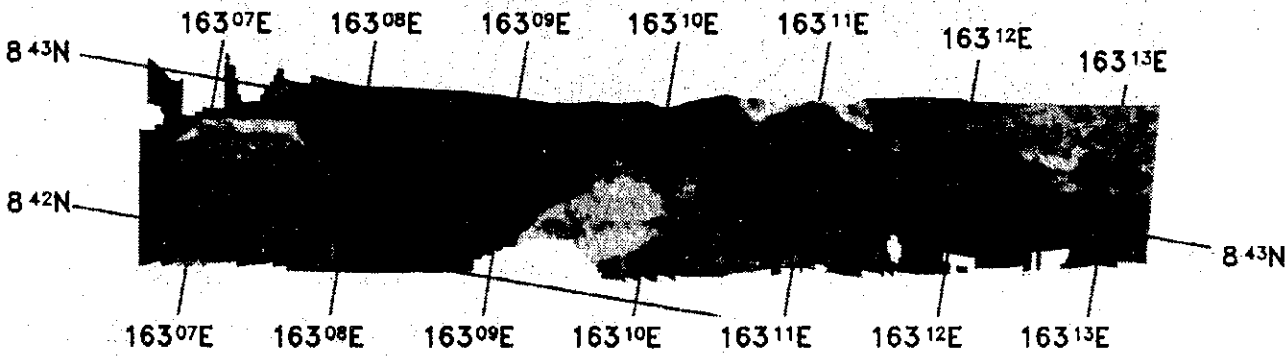
Fig. 3-4-1(2) Results of side scan sonar survey of MS11 area



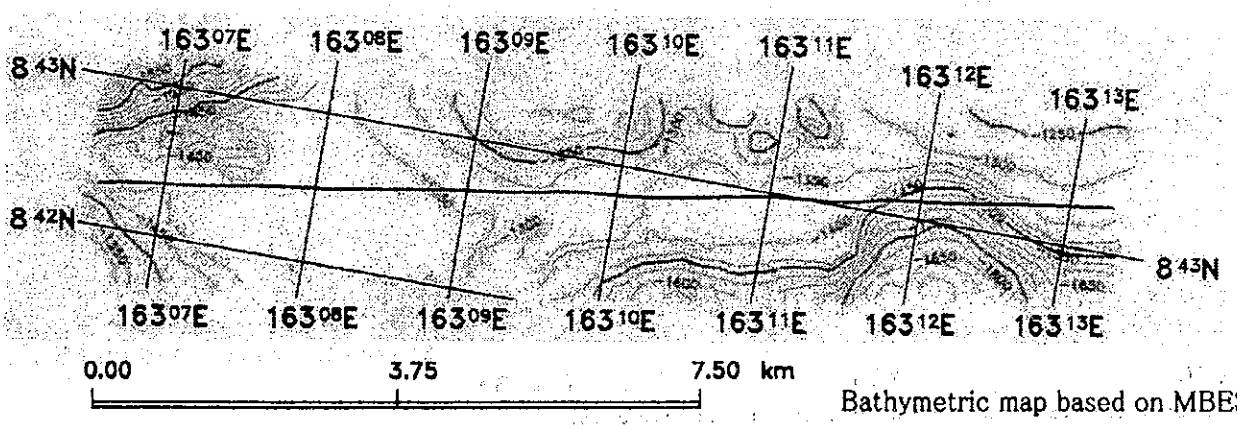
Sidescan Image



SBP profile



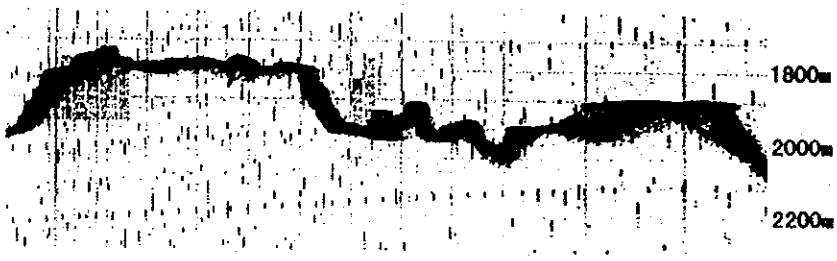
Acoustic reflection image based on MBES



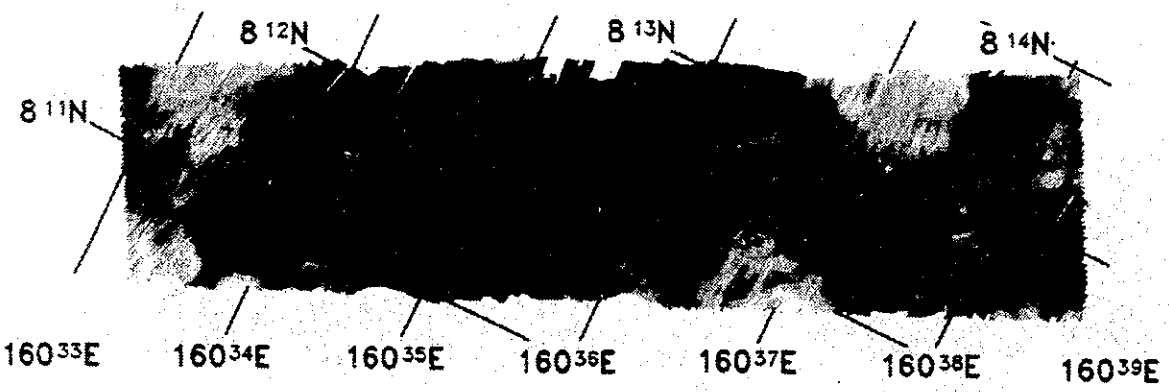
Bathymetric map based on MBES

Fig. 3-4-1(3) Results of side scan sonar survey of MS12 area

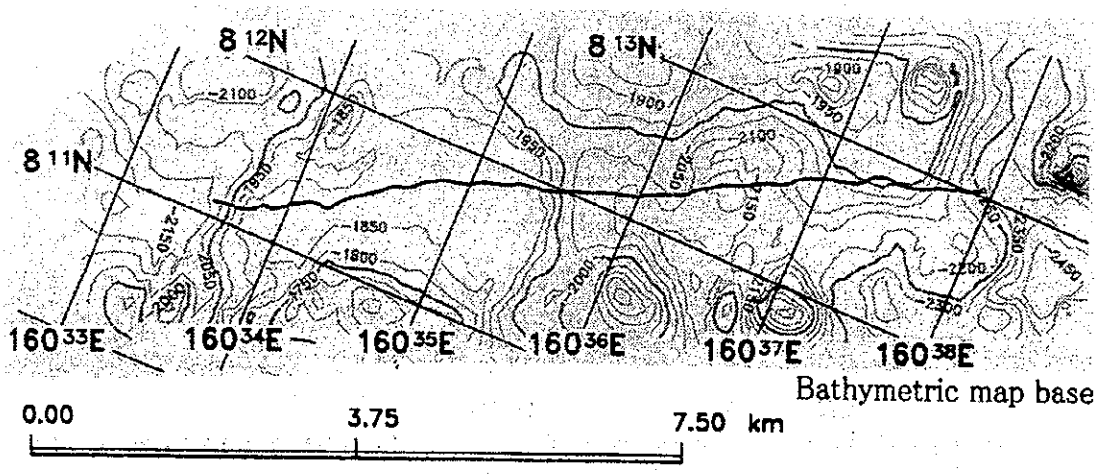
Sidescan Image



SBP profile



Acoustic reflection image based on MBES



Bathymetric map based on MBES

Fig. 3-4-1(4) Results of side scan sonar survey of MS13 area

3－5 Distribution of Unconsolidated Sediments

The distribution of unconsolidated sediments of each area is summarized from the results of MBES acoustic pressure map, SBP and SSS survey as follows.

1) MS10 area

The summit of this seamount is covered by unconsolidated sediments from the peripheral to the central parts and a dome structure is formed. The sediments are thickest in the center of the summit exceeding 50m. There are almost no bedrock outcrops on the summit. The upper slope is steep with average inclination of over 20° and bedrock is widely exposed and sediments are almost non-existent. The slope becomes gentle downward and unconsolidated sediment cover thickens accordingly.

2) MS11 area

The summit is covered by thick unconsolidated sediments and although the depth of the bedrock is not clear, the thickness of the sediments in the central part is inferred to exceed 90m. There are, however, scattered occurrences of pinnacles on the summit and bedrock exposures and thin sediments are recognized near the pinnacles. The sediments generally thinly cover the peripheral parts, but there are exposures in the valleys. The slope is also generally covered by thick unconsolidated sediments with the exception of the upper part, but there are exposures on the pinnacle slopes.

3) MS12 area

The summit is covered by thick unconsolidated sediments and has a dome structure. The sediments of the thickest part exceeds 120m. The center of sedimentation, however, is toward the northeast of the summit and flat outcrop surfaces are observed at the north-south protrusion on the western side of the seamount, southern and western sides of the summit. The upper to middle slope is steep with average gradient exceeding 17°, sediments are hardly observed and bedrock is inferred to be widely exposed.

4) MS13 area

This is a rugged guyot with many relief on the summit. The summit north of 8° 20' N is wholly covered by thick unconsolidated sediments. The seamount has gentle slope from the summit to the base. Exposed pinnacles are scattered to the south of 8° 20' N. The sediments in the depressions among the pinnacles are generally thin.

Chapter 4 Geology

4 – 1 General Geology

The oceanic islands and seamounts of the Marshall Islands were formed by volcanic activity over hot spot which is believed to be the uprising spot of the mantle material. Thus the older volcanoes move on the plate and cease volcanism while the hot spot is immobile and a new volcano is formed over it. This process continues repeatedly and the volcanic islands and seamounts are aligned linearly. The present Pacific Plate is moving westward, but when the seamounts of the study area were formed, the plate is believed to have been moving north-northwestward from the alignment of the volcanoes. Therefore, the age of the seamounts become older to the north in the study area.

In the Central Pacific near the equator, the volcanic activity on the seafloor began during 105~85Ma, and it is believed that islands and atolls were formed and shallow sea volcanism occurred during 85~80Ma (Hein et al., 1988). The volcanic rocks which form these seamounts have different features from the mid- oceanic ridge basalt (MORB), which form oceanic ridges, and are called oceanic island basalt (OIB).

The seamounts of the four areas surveyed are formed by basalt and basaltic clastics with occasional association of limestone and sediments. The exposed bedrocks on the seafloor are often covered by iron and manganese oxides, and these are called manganese crusts. The summits of the guyots, with the exception of the peripheries, small hills, and slopes, are covered by thick unconsolidated foraminifera sand. On the slopes of these seamounts, secondary sediments are considered to be predominant due to denudation and water flow, while foraminifera sand are deposited on gentle slopes.

The target of the survey is the manganese crusts which cover the bedrock and are exposed on the seafloor. These crusts are ferromanganese oxides similar in nature to the manganese nodules which occur on the deep ocean floor. The significant characteristics of the manganese crusts are that they contain 0.5~1.5wt% of cobalt which is considerably higher than the average 0.2wt% content of the nodules. Thus they are sometimes called cobalt-rich manganese crusts. The relatively high content of platinum (0.1~0.3ppm) is also a notable feature of these crusts. The thickness of these crusts varies significantly by the topography, geology, water depth, morphology and location of the seamounts, and other factors. Their average thickness in the study area is about 2cm with a maximum exceeding 10cm. The results of the investigation on the geology, petrology and manganese crusts will be presented in the appropriate sections of this report.

4 - 2 Results of Sampling

Sampling of cobalt-rich crusts, rocks, and unconsolidated sediments was carried out in each area using; chain bag dredge (CB), arm dredge (AD), and gravity large corer (LC).

Sampling was carried out at 61 sites in the four areas of MS10~13. Dredging was done at 49 sites and large corer was used at 12 sites. Total number of sampling carried out in the Marshall Island waters including those of 1996 is at 180 sites in 13 areas of these dredging was done at 127 sites and LC at 53 sites.

In this chapter, description of rocks and unconsolidated sediments collected by dredging and coring will be reported together with the outline of the collected samples of each area.

The location of sampling is shown in Figure 4-2-1 (1)~(4), and the geological outline of the areas in Table 4-2-1. Also the outline of sampling is laid out in Appendix Table 1.

4-3 Collected Samples

(1) Rocks

The rock samples collected during the present cruise are; basalt, limestones including phosphatized rocks, tuff, and pumice. The outline of geology is laid out in Table 4-2-1, and the collected samples and the water depth of the sampling sites are shown in Appendix Table 2(1)~(4) . Of the samples collected, seven basalt samples which are the substrate of crusts and cobble crusts, one basalt pebble from calcareous conglomerate, and two hyaloclastite samples; a total of ten samples were studied by thin section microscopy. The results of microscopic study are shown in Table 4-3-1. Description of the rocks are appended. Photographs of the typical rock samples are laid out in Figure 4-3-1(1)~(5), and description of microscopical studt is shown in Appendix Table 3 .

The characteristics of these rocks are described below.

1) Basalt (Fig. 4-3-1(1)~(5), Photos A~E)

Basalt was collected from the summit peripheries and slopes of all seamounts in the four areas surveyed. From the seamount in MS13 area, basalt was collected together with hyaloclastite near the pinnacles in the central part of the summit.

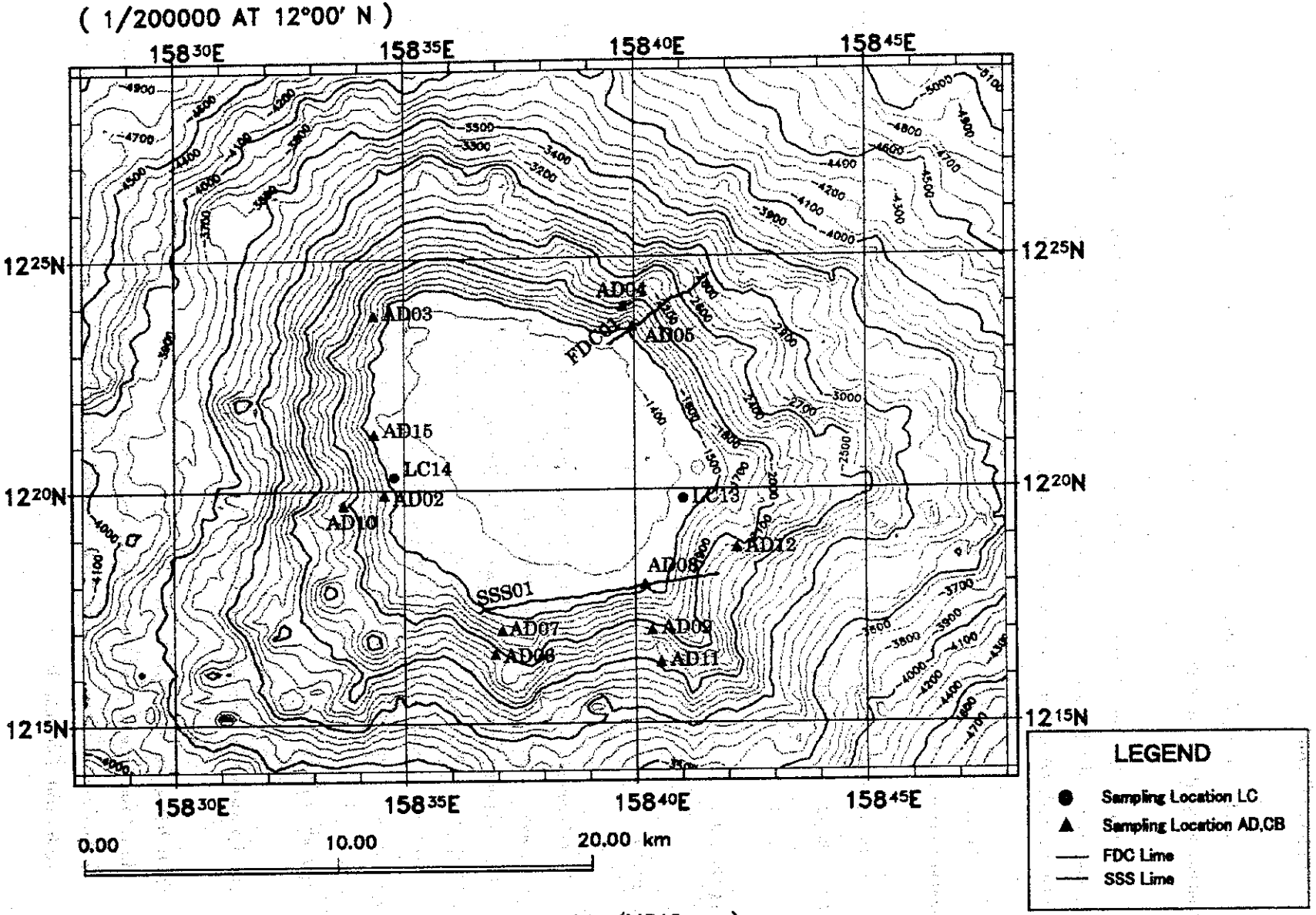


Fig. 4-2-1(1) Location map of sampling sites (MS10 area)

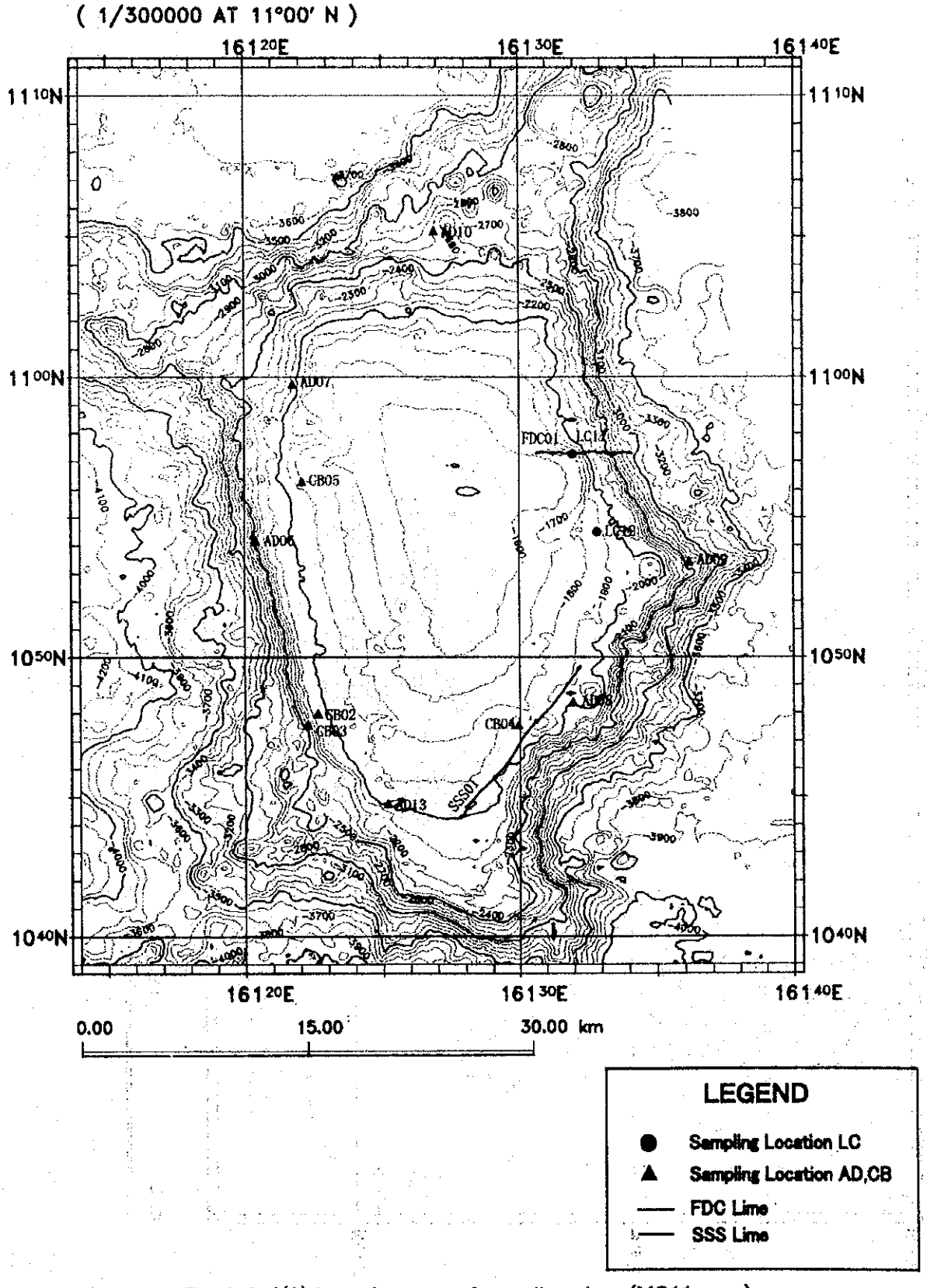


Fig. 4-2-1(2) Location map of sampling sites (MS11 area)

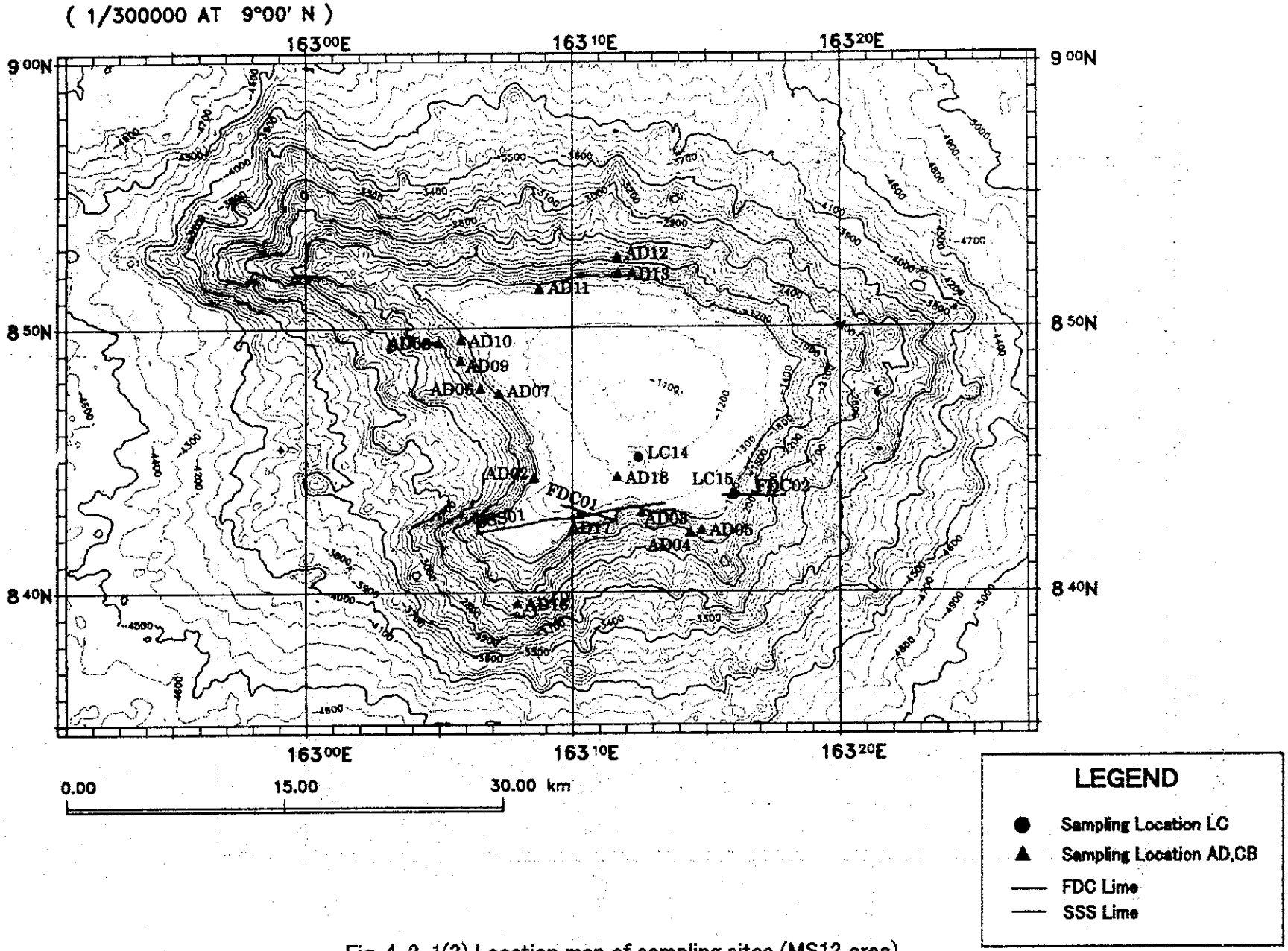


Fig. 4-2-1(3) Location map of sampling sites (MS12 area)

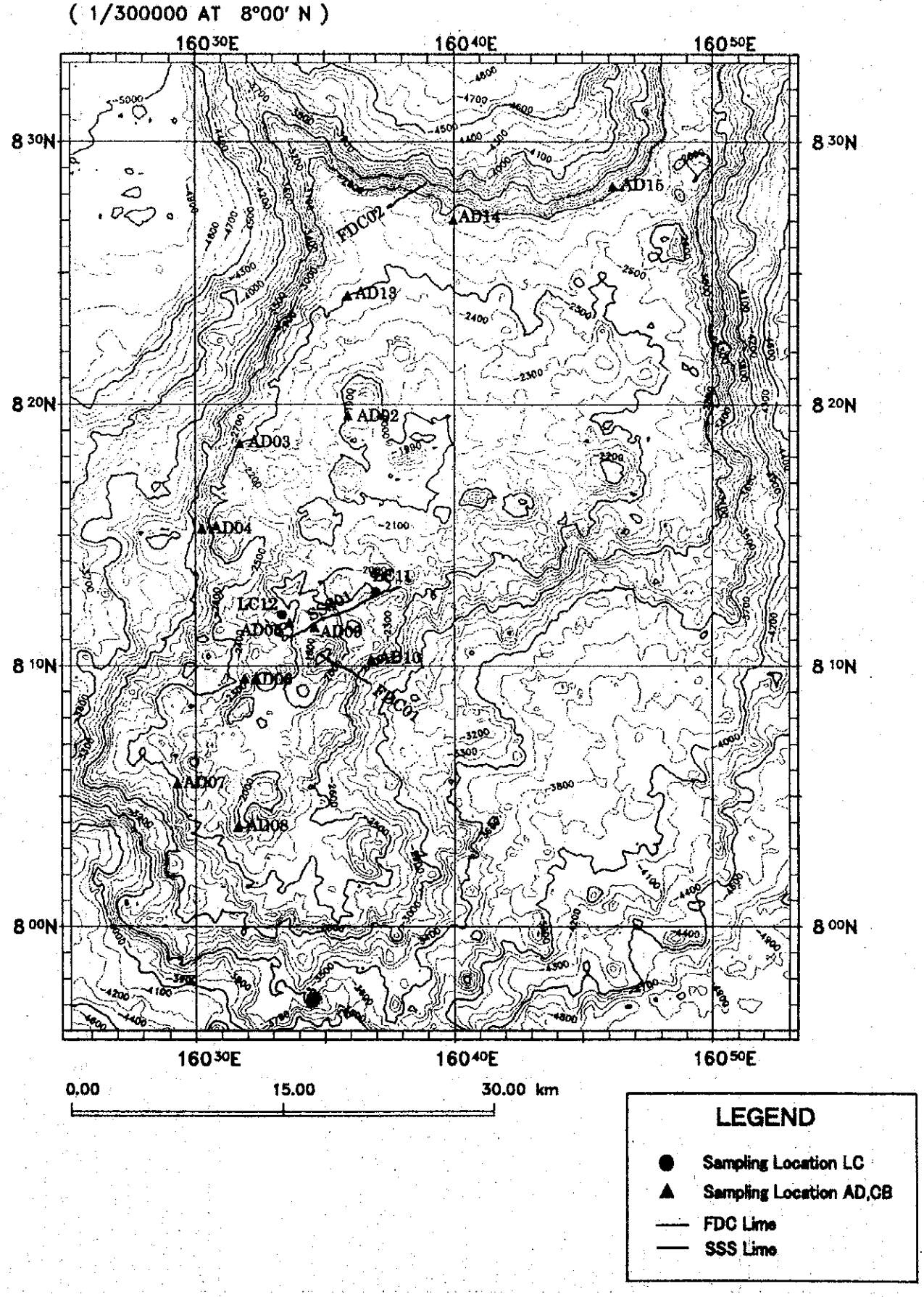


Fig. 4-2-1(4) Location map of esites (MS13 area)

Table 4-2-1 Summary of Geology of Each Area

Area	Seamount topography (water depth)	Topographic division	Basement geology	Basalts	Limestones	Tuffs	Sediments & exposures	Crust summary
MS10	Guyot (dome summit) Planar shape oval, NW slope has few ridges. Ridges on observed SW～NE side. Pinnacles on summit and SW ridges. (Shallowest : 1,292m) (Summit : <1,500m)	Summit.	Basalt, foraminiferal calcareous conglomerate.	Aphyric, porous rocks dominant.	Foraminiferous limestone, contain subrounded～flat basalt pebbles.		Sediments cover entire summit excluding pinnacles, periphery thin.	Crust from summit periphery average thickness over 60mm. Collected maximum 100mm.
		Upper slope.	Basalt, foraminiferal calcareous conglomerate, tuff breccia. Basalt predominant.	Phyric, compact and vitreous rocks mixed.	Foraminiferal calcareous conglomerate below 1,800m depth. Contain angular basalt pebbles.	Occur below 1,800m depth.	Sediments almost nil, generally bedrock exposed.	Crust over 20mm thick collected at various sites on slope. Maximum 46mm, 115mm cobble crust collected at a SE slope ridge.
MS11	Guyot (dome summit) Rectangular shape with N-S long axis. Relative height low t about 2,700m. Terraces extend below 2,500m in NW, NE and SE side. The NE terrace is a saddle continuing to a seamount in the north. (Shallowest : 1,495m) (Summit : <2,100m)	Summit.	Basalt.	Fine grained, plagioclase pyroxene phenocrysts.		Silty tuff distributed locally	Cover summit thickly. Relatively thin near pinnacles. Outcrops. Exposures observed in parts of summit periphery.	Many crust samples exceeding 50mm collected from summit periphery. Also 110mm cobble crust collected from summit periphery.
		Upper slope.	Basalt and foraminiferal limestone.	Fine grained, compact, mixture of phyric and aphyric.	Fine grained, soft foraminiferal limestone. Some contain micronodules.		Covered generally by sediments except the exposures on the uppermost slope.	Collected crusts are mainly 20～25mm. 140mm crusts collected from eastern slope.
MS12	Guyot(dome summit). Summit, oval sloped with 25km in WNW-ESE direction, oval-shaped about 15km in short axis. The base is almost circular. Unconsolidated sediments abundant in central part of summit with exception of pinnacles. Seafloor smooth. Regarding the slope, upper part is steep where ridges are developed along the long axis and in the NW direction perpendicular to the long axis. The inclination, however, gradually decreases downward. Terraces developed below 3,000m. Many small ridges occur on the N to E side and pinnacles occur sporadically. (Shallowest : 1,037m) Summit : <1,400m)	Summit.	Basalt, foraminiferal calcareous conglomerate, tuff, hyaloclastite in a northern part. Reefal limestone confirmed.	Mixture of compact, fine grained and porous rock. Many with minute phenocrysts.	Foraminiferal calcareous conglomerate on summit periphery and near pinnacles. Pebbles are basalt, rounded and angular. Reefal limestone pebbles are confirmed in sample from southern periphery.	Greenish-gray, fine-grained, compact tuff collected from near pinnacles. Hyaloclastite-like pyroclastic rocks also collected from near pinnacles.	Thick unconsolidated sediment cover on summit center. But bedrock exposed on western peninsula-like protrusion, and southern and western periphery.	Crusts tens of mm thick collected from various sites of the summit periphery exposures. Also cobble crusts exceeding 100mm collected from western and southern summit periphery. Crusts exceeding 20mm collected near summit pinnacles.
		Upper slope.	Basaltic and foraminiferal calcareous conglomerate. Reefal limestone on uppermost western slope.	Compact/porous, aphyric/phyric material mixed. Aphyric porous rocks somewhat dominant.	Foraminiferal calcareous conglomerate. Two types, those with subrounded basalt pebbles and those with angular basalt pebbles. Generally phosphatized and hard. Reefal limestone coarse grained and porous, but hard and contain abundant shell fragments.		Unconsolidated sediments cover eastern and southern slope, but very locally on western nd northern slope where bedrock exposures extensive.	Several tens of mm crusts collected from various sites of slope. No variation of thickness by water depth or locality. Maximum 140mm thick.
		Middle slope	Basalt, foraminiferal limestone and tuff.	Fine grained, porous rocks predominant. Mainly aphyric, but some with minute plagioclase phenocrysts.	Foraminiferal calcareous conglomerate. Pebbles mainly angular basalt with some crust fragments. Generally phosephatized and hard.	Pumiceous tuff breccia, contain angular basalt granules.	Generally covered by unconsolidated sediments, but uneven, many bedrock outcrops.	Several tens of mm crusts collected at various sites, many exceed 50mm. Maximum 96mm from western slope.
MS13	Guyot(rugged) Pinnacles sporadic on summit, rugged topography. Summit somewhat rectangular with about 50km long axis in NNE-SSW, short axis about 25km. Summit topography complex from north to south. Summit inclination somewhat steeper than general guyots. Slope gentle except ridges in NE and NW edges. Unconsolidated sediments thick on terraces from north to east forming gentle slope. (Shallowest : 1,387m) (Summit : <2,700m)	Summit	Basalt, foraminiferal calcareous conglomerate, and tuff.	Mixture of fine-grained, compact and porous rocks. Aphyric, phenocrysts if any are minute and not clear. Samples containing acicular plagioclase collected rarely.	Foraminiferal calcareous conglomerate. Subrounded～subangular basalt pebbles. Some without pebbles. Matrix contain micronodules, pelitic, fragile, generally not phosphatized.	Collected at foot of pinnacles somewhat north of summit center. Fine grained, compact, but weathered and fragile.	Pinnacles scattered on summit exposed. Sediments on depressions between pinnacles thin.	Crusts exceeding 100mm collected near pinnacles. Thick cobble crusts scattered on depressions between pinnacles. Maximum 160mm thick.
		Upper slope.	Basalt, foraminiferal limestone, and tuff breccia.	Mixture of fine-grained, compact, and porous rocks. Almost all aphyric. Samples with acicular plagioclase collected rarely.	Foraminiferal limestone. Pelitic, fragile. Contain micro nodules. Phosphatization almost nil.	Collected from western slope. Contain basalt granules. Matrix fine grained, compact, strongly weathered, partly argillized.	Generally covered by thick sediments.	Existence of crusts in exposures confirmed by FDC. Crusts 35mm collected from uppermost western slope (correspond to the summit periphery depthwise).

Table 4-3-1 Results of microscopic observation for rock thin sections

Sampling location No.	Sample code	sample No.	Rock	structure	Phenocryst content	Alteration	Phenocryst minerals: Plagioclase	Olivines	Augite	Orthopyroxene	Clinopyroxenes	Opaque mineral	Spinel	Matrix: Plagioclase	Olivines	Clinopyroxenes	Opaque mineral	Volcanic glass	Altered minerals: Smectite	Idingsite	Silica minerals	Zeolite	Chlorite	Note	Description (unaided eyes)
98S MS10AD03	F	T01	Vitreous basalt	Phyric,porous. Weak flow structure Spherulitic~amygdaloidal texture.	10 ~ 20%	weak	◎											◎	×		×			Volcanic grass partly altered to clay minerals such as smectite.	Brown,crushed,frangile.Acicular plagioclase.White veins developed throughout.Crushed milky white clay minerals observed.
98S MS10AD05	F	T01	Altered basalt	Phyric. Flow structure.	40 ~ 45%	strong	◎	○	○									◎	◎		○			Vitreous matrix partly devitrified, altered to smectite,weakly silicified.	Ruddish brown,autobrecciated.White clayey (or quartz) veinlets in network.
98S MS10AD08	C	T03	Olivinee basalt	Spherulitic micro-phyric texture	10%	intermediate	○	○								◎	○	○	○	○				Smectized (vitreous matrix),iddinsitized (replacing olivinee). Smectite veins developed.	Brown,white veinlets developed. Prismatic euhrdral crystal fragments on sample surface.Black,white spherulitic texture developed.
98S MS11AD05	C	T01	Porphyritic spherulitic olivinee basalt	Phyric, vitereous matrix. Phenocryst /matrix plagioclase show weak flow structure.	12%	strong	○	○				×		◎			○	◎	○	○				Phenocrysts mostly altered to clay minerals such as smectite.	Brown,compact clayey. Consist of white prismatic plagioclase phenocrysts.
98S MS11AD09	D	T01	Microphyric spherulitic olivinee basalt	Smectite fills voids with spheruliyic~amygdaloidal texture.	20 ~ 30%	weak	○	○				○		○			○	◎	+	+	+			Olivinee phenocrysts altered pseodomorph. Matrix divitrification weak.	Greenish brown, compact. Blackish brown spherulitic texture observed.White incrustation on surface.
98S MS12AD04	H	T03	Microphyric spherulitic olivinee basalt	Phyric,vitreous matrix, porous. Voids filled by smectite with spherulitic~amygdaloidal texture.Phenocrysts/matrix plagioclase show clear flow structure.	40%	intermediate	◎	○	○					◎			×	○	+					Generally weakly altered except mafic minerals.Dvitrification also weak.	Reddish brown, porous (vesiculation?), reddish yellow brown incrustation on surface. Coarse-grained (n¥max 7mm) phenocrysts (plagioclase) observed.
98S MS12AD07	A	T01	Basaltic pyroclastic rocks	Clastic pebble texture.		strong													◎		○	○		Pisolitic, oolitic~ spherulitic smectite formed.	Coarse angular pebbles maximum 8cm. Basaltic pebble with 2 types of alteration. Some pebbles with bleached surface by alteration. Quartz/apatite veins developed. Matrix'diverse;glassy~ sandy.
98S MS12AD16	B	T01	Basaltic pyroclastic rocks	Vetreous matrix	35%	weak	○					◎						◎	◎		○			Alteration strong for pebbles, smectite developed. Alteration weak for matrix, volcanic glass remain.	Consist of subangular pebbles of basaltic pyroclastic rocks.Pebble are diverse such as basaltic pebbles and globigerina carbonatic psammitic mudstone pebbles.
98S MS13AD02	C	T02	Hyaloclastite	Clastic, network veins developed. Pockets of calcite.		intermediate						◎					×	◎	◎		○			In matrix, smectite and silica minerals formed as cementing matter (colloform, void filling).	Brown hyaloclastite. Do not pebbles. Coarse grained ~ pisolitic. Voids (milky white incrustation inside) observed locally.
98S MS13AD03	A	T01	Aphyric porous basalt	Aphyric porous. Matrix phyric. Plagioclase shows weak flow structure.	few	strong	+	+	+					◎					○					In phenocrysts, clinopyroxene is argillized (smectite), alteration significant. Matrix partly argillized (smectite), but alteration generally weak.	Brown, compact, porous(brick-like appearance). Gravish white filling observed locally.

Regend ◎:many ○:intermediate ×:few +:rare

From the three seamounts in MS10~MS12 areas, basalt was collected as substrates of thick crusts and cobble crusts, and very few of them were pebbles with coating level of crust coverage. In the seamount in MS13 area, thick crusts and cobble crusts with basalt substrate have been collected from near the pinnacles in the central part of the summit, but basalt samples from the summit periphery and the upper slope have relatively thin cobalt-rich crust and many basalt samples were collected with only coating of crust. Also in three areas besides MS11, basalt occurs as pebbles of the foraminiferal limestone conglomerate.

Most of the samples collected are weathered to brown~grayish brown, and fresh rocks with dark gray color are rare. Most samples have aphyric texture or minute phenocrysts, and those with clear phenocrysts are rare. Phenocrysts are mostly prismatic plagioclase of several millimeters, rarely mafic minerals such as pyroxene of about 2mm are observed. Only several basalt samples have been confirmed to contain coarse-grained phenocrysts in this study area. Plagioclase phenocrysts are relatively fresh, but pyroxene is mostly altered by weathering.

Fine-grained and compact to vitreous matrix occur somewhat more often than the porous ones. Most of the porous matrix have scattered pores of about 1mm diameter and some of these are filled with zeolites, quartz, and nephrite.

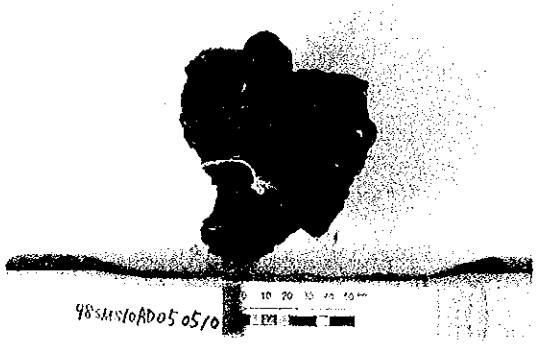
Olivine phenocrysts are observed by thin section microscopy in basalt samples from the three seamounts in MS10~MS12 areas, but they are altered mostly to clay and they cannot be identified by unaided eyes. Also augite was not recognized in the basalt from MS11 seamount, but all basalts from the three areas have plagioclase phenocrysts with volcanic glass and minute plagioclase matrix, and large difference were not found by microscopic studies. Basalt samples recognized to be least weathered by unaided eyes were selected from each seamount for microscopic observation, but phenocrysts and matrix of all samples showed argillization and corrosion microscopically.

2) Limestone (Fig. 4-3-1(4), (5), Photo G~L)

Limestone was collected from each area as the substrate of crusts and cobble crusts, nuclei of nodules, and coated pebbles.

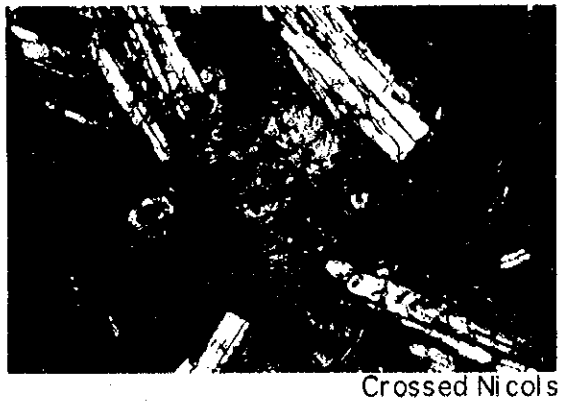
In the MS10 and MS12 areas, limestone was collected as substrate of crusts and cobble crusts in a wide area from the summit peripheries to slopes, but in MS11 area, only one sample was collected from the upper slope of the seamount. And in MS13 area, it was collected as crust substrate, but the amount was smaller than basalt and hyaloclastite samples.

Foraminiferal limestone and foraminiferal calcareous conglomerate occur in all seamounts of the Marshall

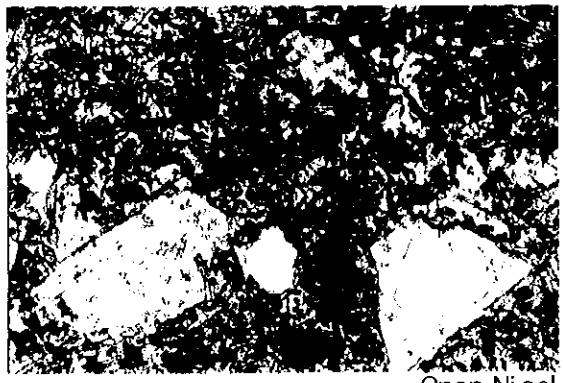


Open Nicol

A. 98SMS10AD05-C
Altered basalt
Crushed, frangile. White veins such as calcareous clay, developed throughout.

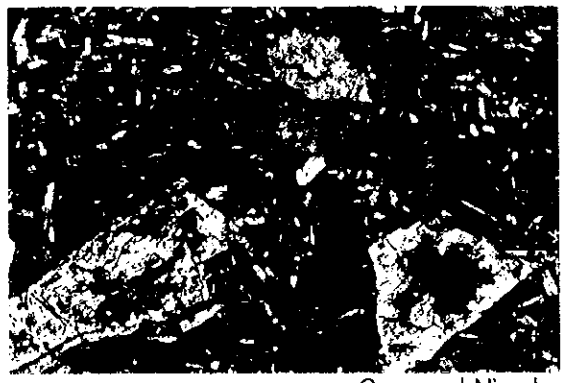


Crossed Nicols



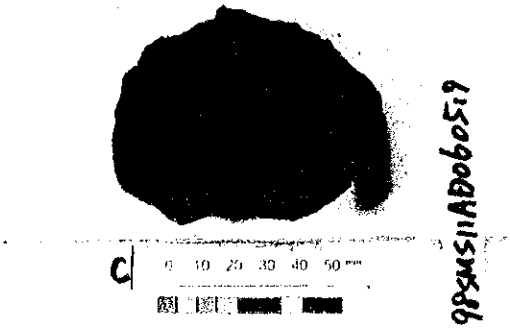
Open Nicol

B. 98SMS10AD08-C
Olivinee basalt
Spherulitic, micro-phyric texture



Crossed Nicols

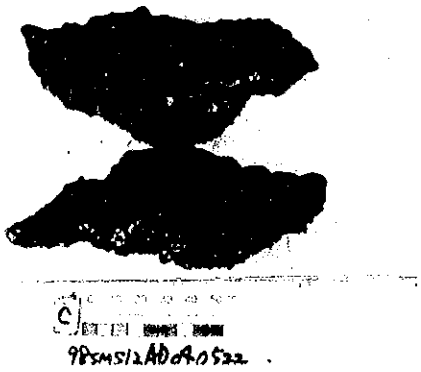
Fig. 4-3-1(1) Photographs of typical rock samples



Open Nicol

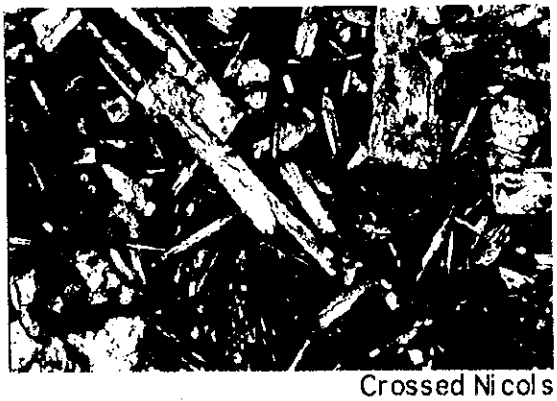
C. 98SMS11AD06-C
Porphyritic spherulitic olivinee basalt
Consist of white prismatic plagioclase phenocrysts.

Crossed Nicols



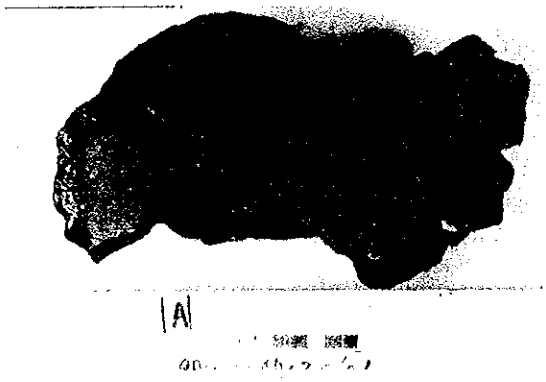
Open Nicol

D. 98SMS12AD04-C
Porphyric spherulitic olivinee basalt
Porphyric, porous. Voids filled by smectite with spherulitic texture.



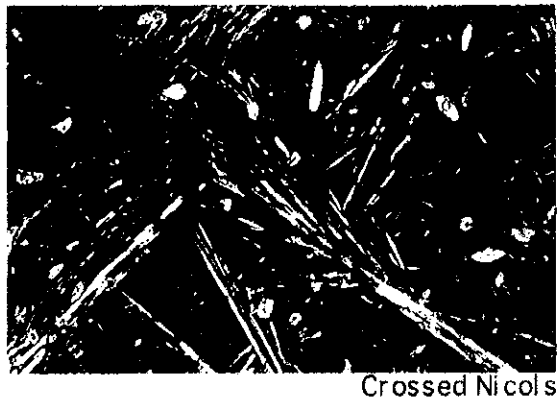
Crossed Nicols

Fig. 4-3-1 (2) Photographs of typical rock samples



E. 98SMS13AD03-A
Aphyric porous basalt
Porous(brick-like appearance),
vitreous matrix.

Open Nicol



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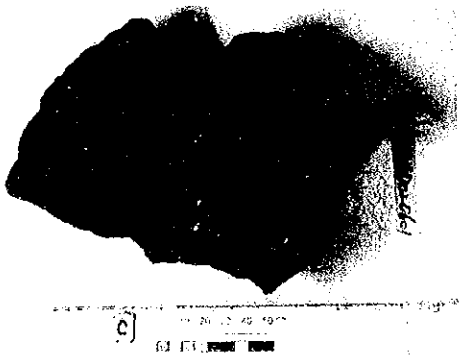
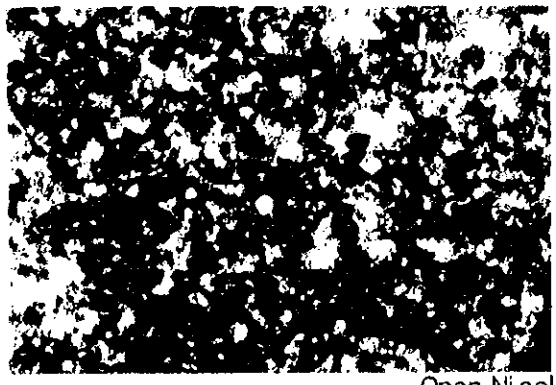
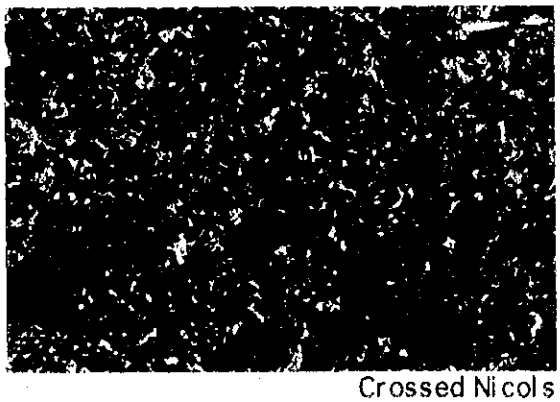


F. 98SMS13AD02-C
Hyaloclastite
Coarse grained ~ pisolitic.
Calcite vein developed network
-like appearance.



Open Nicol



Crossed Nicols

Fig. 4-3-1 (3) Photographs of typical rock samples

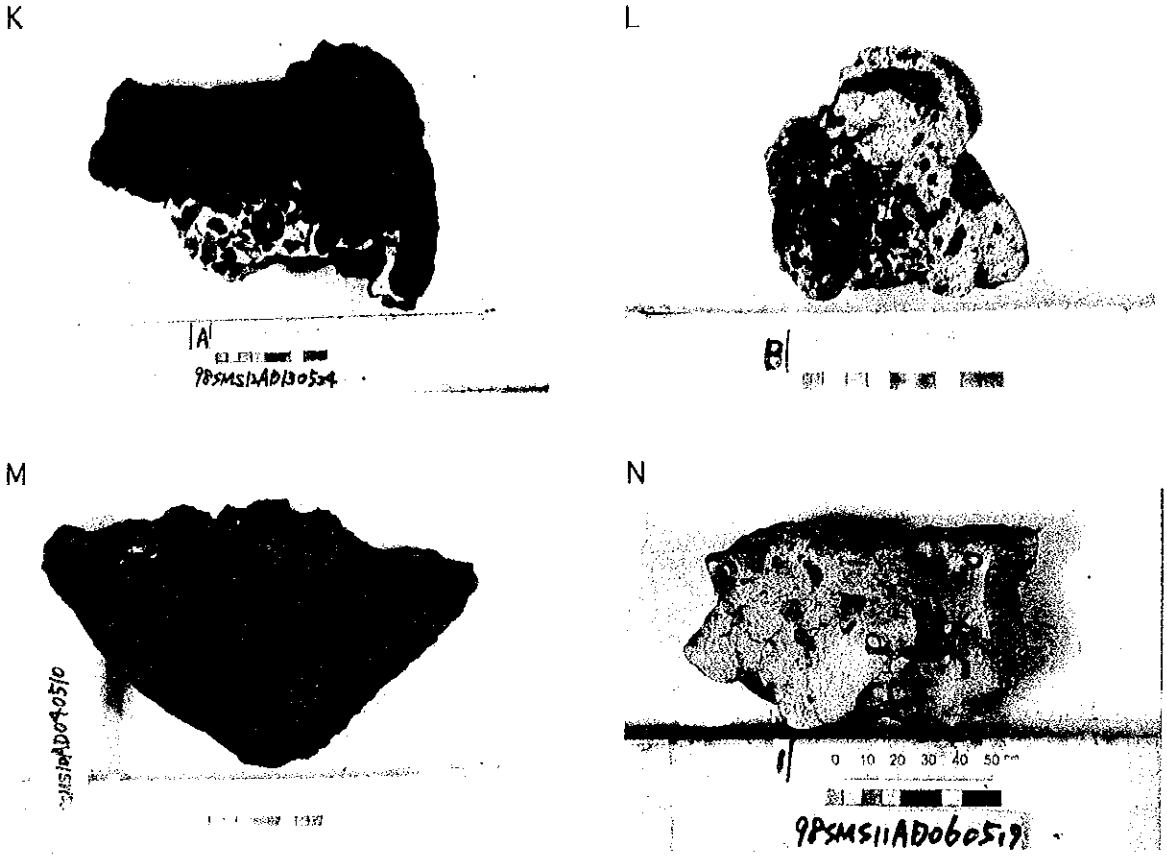
G. 98SMS10AD05-B
Globigerina carbonate conglomerate
Contains basalt gravel.

H. 98SMS10AD08-B
Globigerina carbonate conglomerate
Contains basalt gravel～breccia.

I. 98SMS10AD09-B
Globigerina limestome
Phosphatized and turned to hard

J. 98SMS12AD05-A
Globigerina limestome
Including white specle, porous for leaching.

Fig. 4-3-1(4) Photographs of typical rock samples



K. 98SMS12AD13-A
Globigerina carbonate conglomerate
Contains coral limestone as gravel.

L. 98SMS13AD14-B
Globigerina limestome
Sandpipe (ϕsome mm) shown

M. 98SMS10AD04-A
Tuff breccia
Contains basalt gravel

N. 98SMS11AD06-I
Sanddy tuff
Fagments of coral and shells occur.

Fig. 4-3-1(5) Photographs of typical rock samples

Island waters. The size, amount, and shape of the pebbles differ by area and locality, and thus the lithology is diverse. But the matrix is generally clayey and is white to pale yellow. Consolidation is high and relatively hard samples are observed. A large portion of these rocks have been strongly phosphatized and many have been altered to pale yellow to pale pink hard apatite. Majority of the conglomerate pebbles are subangular to subrounded rounded basalt pebbles, but many from the seamount slopes contain angular pebbles.

The reefal limestone sampled from MS12 seamount summit periphery is white. It is generally coarse grained and hard, but parts of it have been washed out into spongy material and some is pale yellow by phosphatization. The structure of reef-building coral can be seen clearly in some of them and some contain abundant shell and other biological fragments. Coral fragments were observed in tuff sample collected from seamount upper slope in area MC11.

3) Tuff (Fig. 4-3-1(3), Photo M,N)

Tuffaceous rocks were collected from all four areas, and their existence was confirmed in many areas of the survey area during the past survey. The tuff in the present area is mostly sandy tuff.

Almost all tuffs were collected as pebbles coated by manganese oxides, but a few samples from upper slope of MS11 seamount and middle slope of MS12 seamount are substrate of crusts and cobble crusts. That from MS11 contains calcareous clay and is the only pelitic and hard tuff, it contains coral fragments.

Tuffaceous rocks consist of tuff breccia which occurs widely on the seamount slope and pumice tuff which occurs near some of the pinnacles on seamount summits of the MS12 and MS13 areas. They both have fine-grained sandy matrix and are yellowish brown to pale yellowish green. They are generally strongly weathered and are fragile. Tuff breccia contain angular basalt pebbles and also mostly subangular to subrounded basalt pebbles.

4) Hyaloclastite (Fig. 4-3-1(3), Photo F)

Hyaloclastite was collected as substrates of crusts and cobble crusts, and nuclei of nodules from the seamounts of MS12 and MS13 areas. In MS12, only several samples were collected by three sampling from summit periphery to upper slope, and concentrated occurrence is unlikely. In MS13 area, hyaloclastite was recovered together with basalt as cobble crust substrate in the depressions between the pinnacles in the central part of the summit.

The sample from MS12 consists of volcanic glass filling the interstices of angular fragments of basalt and siliceous rocks, but the matrix is strongly weathered and has the appearance of tuff breccia. That from

MS13 area has the appearance of aphyric dolerite. Microscopically, both are strongly weathered and MS12 samples are oolitic and MS13 samples contain vein smectite.

5) Pumice

Pumice in this area is highly foamed and is pale gray.

Pumice was collected only from two seamounts, MS05 and 07, during the past survey, but it was recovered from all four seamounts during the present survey as pebbles in unconsolidated sediments.

(2) Unconsolidated sediments

Large corer (LC) sampling was carried out at 12 sites of four seamounts.

The objectives of the LC sampling was to collect the bottom sediments, cobalt-rich crusts, and to observe the seafloor conditions by seafloor photography. Therefore this was carried out in some cases where bedrocks are inferred to be exposed and bottom sediments were not collected. During the present cruise, bottom sediments were collected from six sites out of the 12. The column of the recovered cores in Appedix Figure 4 (1),(2). The nature of the cores collected by LC sampling and the seafloor conditions by seafloor photographs are summarized in FTable 4-2-3 and photgraphs are shown in Figure 4-3-2(1),(2).

The six sites where bottom sediments were recovered are; four site in the piedmont to the base of the seamounts and two in the summit peripheral parts. The samples from the piedmont and the base are dark brown clay and pale brown calcareous clay.

The dark brown clay was collected in MS10LC01 (5,516m water depth) and MS12LC01 (4,516m). They are generally homogeneous and the water content percentage is slightly lower in the in the inner parts, and the consolidation tends to become stronger toward the lower part of the samples.

Calcareous clay was collected in MS11LC01 (4,353m water depth) and MS13LC01 (4,516m). The grain size is mostly fine, but some 1mm size foraminifera are mixed. Generally the water content percentage is low and the samples are soft.

Samples MS10LC14 (1,468m water depth) and MS12LC14 (1,130m) were collected at the summit peripheries and they consist of white to pale brown foraminiferal sand. The grains are 0.5~1.0mm and spherical. The shape is well proportioned near the surface, but the foraminifera shells become thin downward and some of the shells are broken crusts. The color is mostly pale brown. The water content percentage is generally high and

Table 4-3-2 LC samples and Seafloor photographs

Area	Sampling	Sampling site water depth	Samples (cm)	Bit deformation	Crust exposure ratio	Crust type	Seafloor surface, crust surface.
MS10	LC01	5,494m	Ooze (352), Nodules.	None	95%	Nodules	Covered by several cm nodules.
	LC13	1,433m	Small crust	Deformed	0%	—	Sand cover.
	LC14	1,488m	Ooze (78), Nodule	Deformed	0%	—	Sand cover, nodule pebbles at 20～50cm intervals.
MS11	LC01	4,353m	Ooze (226).	None	Photo quality poor	—	—
	LC11	1,690m	Small crusts.	Deformed	65%	Crust	Botryoidal, surface covered by sand.
	LC12	1,867m	Small crusts.	Deformed	3%	Crust	Botryoidal, surface covered by sand.
MS12	LC01	4,545m	Ooze (335), Nodules.	None	90%	Nodules	Covered by around 5cm nodules.
	LC14	1,177m	Foraminiferal sand (50*).	None	Photo quality poor	—	—
	LC15	1,383m	Small crust fragments	Deformed	Photo quality poor	—	—
MS13	LC01	4,069m	Ooze (215), Nodules..	None	20%	Nodules	Sporadic occurrence of nodules under 5cm.
	LC11	2,029m	Ooze stuck on bit.	Deformed	Photo quality poor	—	—
	LC12	2,079m	Foraminiferal sand stuck on bit.	Deformed	Photo quality poor	—	—