

Chapter 3 Results of the Survey

3 - 1 Outline and Seafloor Topography of the Marine Area of the Cook Islands

(1) Outline of the Cook Islands sea area

This survey area is located in the southwestern part of the Pacific Ocean and extends south-southeastward in a narrow zone from the Tongareva island of the western margin of the South Penrhyn Basin to the Southwest Pacific Basin (Fig. 3-1-1). Most of the survey area is included in the western margin of the South Penrhyn Basin and the southern part is in the Samoa Basin and the South Pacific Basin.

On the western side of the area, a submarine ridge extends in the NNE-SSW direction from the eastern edge of the Manihiki Plateau. This ridge borders the western margin of the survey area. The Samoa Basin lies to the west. Palmerstone, Aitutaki, Mangaia and other islands of the South Cook Islands extend in the WNW-ESE direction across the survey area and form the boundary with the South Penrhyn Basin to the north and South Pacific Basin to the south.

The survey area is in the southwestern part of the Pacific Plate and the seafloor consists of Early Cretaceous oceanic crust and pelagic sediments, which cover the crust. The Manihiki Plateau occupies an area of 500,000km² with average relative height of 4,000m on the oceanic crust. It is considered to have formed by a huge Early Cretaceous basaltic lava activity (Heezen et al., 1965; Schlanger et al., 1974; Winterer et al., 1974). The South Cook Islands form a chain of islands extending in the NW-SE direction together with the Austral Islands to the southwest. These islands were formerly believed to have been formed by Cenozoic Hot Spot activity of the Pacific Plate moving northwestward (Morgan, 1972). But subsequently, the ages of the volcanic rocks of the islands became clear (Dalrymple et al., 1975; Turner and Jarrand, 1982) and it is now understood that these islands cannot be explained by a simple single Hot Spot model. According to Dalrymple et al., (1975), and Turner and Jarrand (1982), the ages of the volcanic islands of the South Cook Islands range quite widely from 1Ma (Quaternary) to 20Ma (Neogene), and volcanism of differing ages are observed even in one island. Thus these islands are believed to have formed by not a single Hot Spot, but by several Hot Spots centered in the Polynesia sea area (Bergersen, 1995).

Nishimura and Saito (1994) classified the pelagic sediments of the northern part of the Penrhyn Basin into: post-Oligocene Unit I, late Paleocene-Eocene Unit II, Cretaceous-early Paleocene Unit III, and showed that a hiatus exists between Unit I and Unit II.

Large amounts of manganese nodules were found in the sea area of the Cook Islands by survey vessels of US and USSR in the 1960's (Skornyakova and Andruschennko, 1974; Glasby and Lawrence, 1974). Subsequently the South Penrhyn Basin has been surveyed most often within the Cook Islands sea area (Backer et al., 1976; Landmesser et al., 1976; Monzier and Missegue, 1977; others). Exson (1981) summarized the results of the manganese nodule surveys in the Cook Island area. He showed that nodules with metal grade exceeding 2% (Ni+Cu+Co)

occur in the South Penrhyn Basin with abundance of more than 30kg/m² in some parts and thus the South Penrhyn Basin was the most promising within the Cook Island sea area. Subsequently Metal Mining Agency of Japan (MMAJ) surveyed the area and clarified that zones of high abundance of manganese nodules occur in the western margins of the South Penrhyn Basin (JICA · MMAJ, 1986, 1987, 1991). Antarctic bottom current has been flowing through Attutaki Passage between the Palmerston and Attutaki Islands into the Pacific Ocean where Penrhyn Basin is located since Eocene time. The manganese nodules in this area are believed to have formed and grew mainly in Paleogene period facilitated by the inflow of this Antarctic bottom current (Usui et al., 1993; Usui, 1994).

(2) Seafloor Topography

This marine area is narrow and is elongated extensively in the NE-SW direction between the Samoa Basin and Southwest Pacific Basin in the south and the northern part is within the southern Penrhyn Basin of the Central Pacific Ocean. The northwest side is adjacent to the extensive Manihiki Plateau (relative height 1,500~2,000m). A linear submarine ridge extending in the NNE-SSW direction (Figs. 3-1-1 seafloor map and 3-1-2 bird's-view map) borders this area and the Manihiki Plateau.

The Samoa Basin in the western part is a 5,000~5,700m deep area bordered by Manihiki Plateau and Palmerston Island. The Basin is deep and the seafloor flat, but many small sea knolls are observed within.

The southern Penrhyn Basin in the north has, on the whole, flat seafloor of 4,900~5,500m deep and it becomes deeper to the north with some troughs deeper than 5,500m to the south of the Penrhyn Island. The characteristics of these sea areas are mentioned below.

<Center Area>

Seafloor topographic survey of this area was carried out by 80 mile track lines in the E-W direction at 4 mile intervals so that the water depth is totally covered by MBES (track line chart Attached Fig. 1). The results are shown in seafloor topographic map (Fig. 3-1-3) and bird's view map (Fig. 3-1-4).

This area was classified as "semi-flat" by the 1986 survey, and many seamounts and sea knolls are observed. Most prominent and representative seamount is observed at 16° 20'S, 159° 33'E in the deepest basin in the southwestern part of the area and its summit is 2,900m deep with relative height of 3,000m. The summit of this seamount is the shallowest part of the area. This seamount is accompanied by many knolls and forms a seamount chain extending in the N30° W direction. Caldera-type depressions are observed at the summits of these knolls. Small pinnacles of about 1 mile in diameter are, also, dominant near this seamount and the seafloor shallower than 5,000m have very complex topography with many undulations (see 3-dimensional map at the vicinity of the seamount Fig. 3-1-5).

At the northeastern end of this area, a small-scale sea knoll chain occurs elongated in the same direction as the above seamount chain and a relatively flat area extend between the two. Here, ridge and trough topography is observed extending in the N60° E direction which crosses the dominant direction of N30° W at right angles.

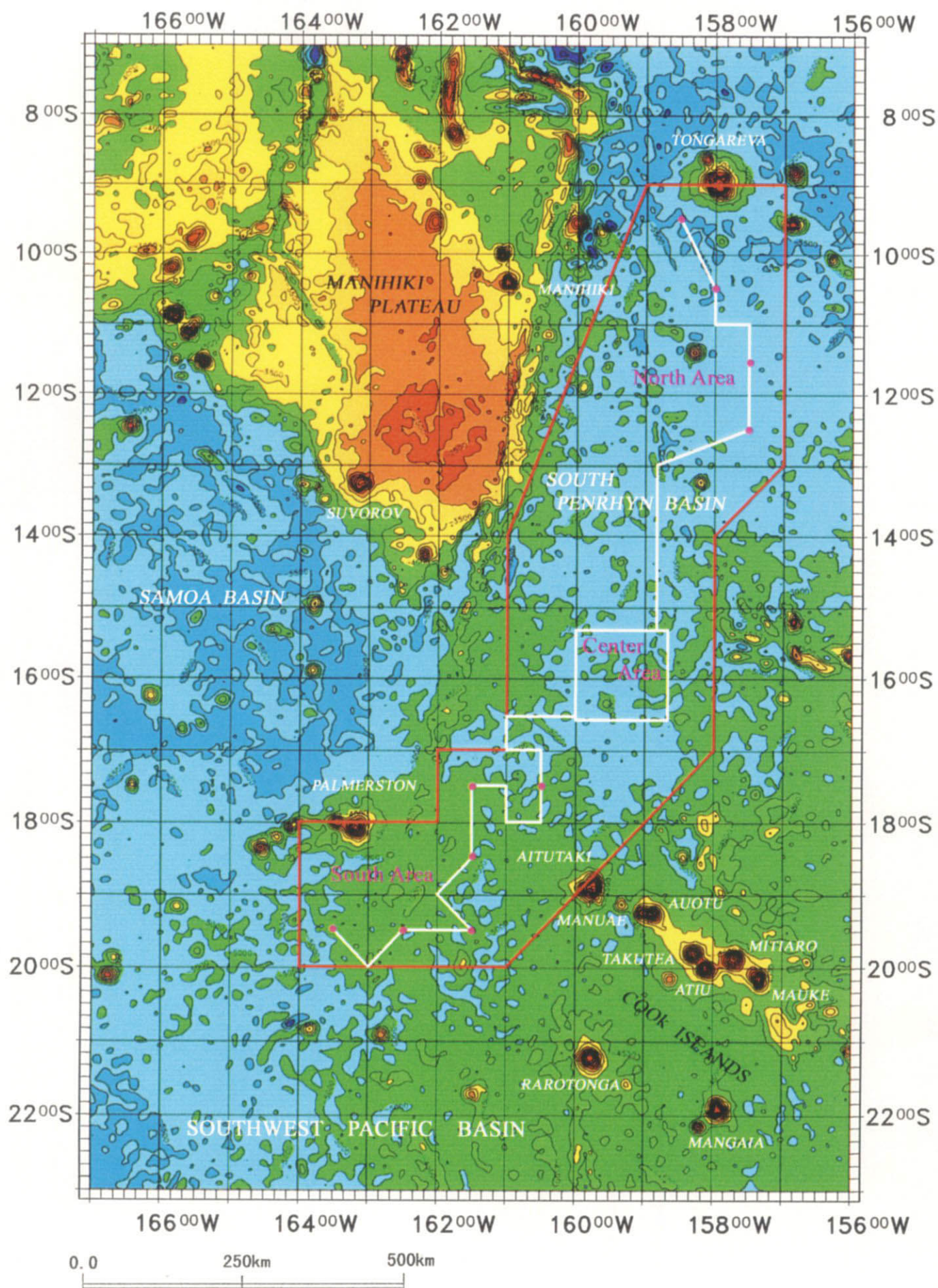


Figure 3-1-1 Location Map of the Survey Area

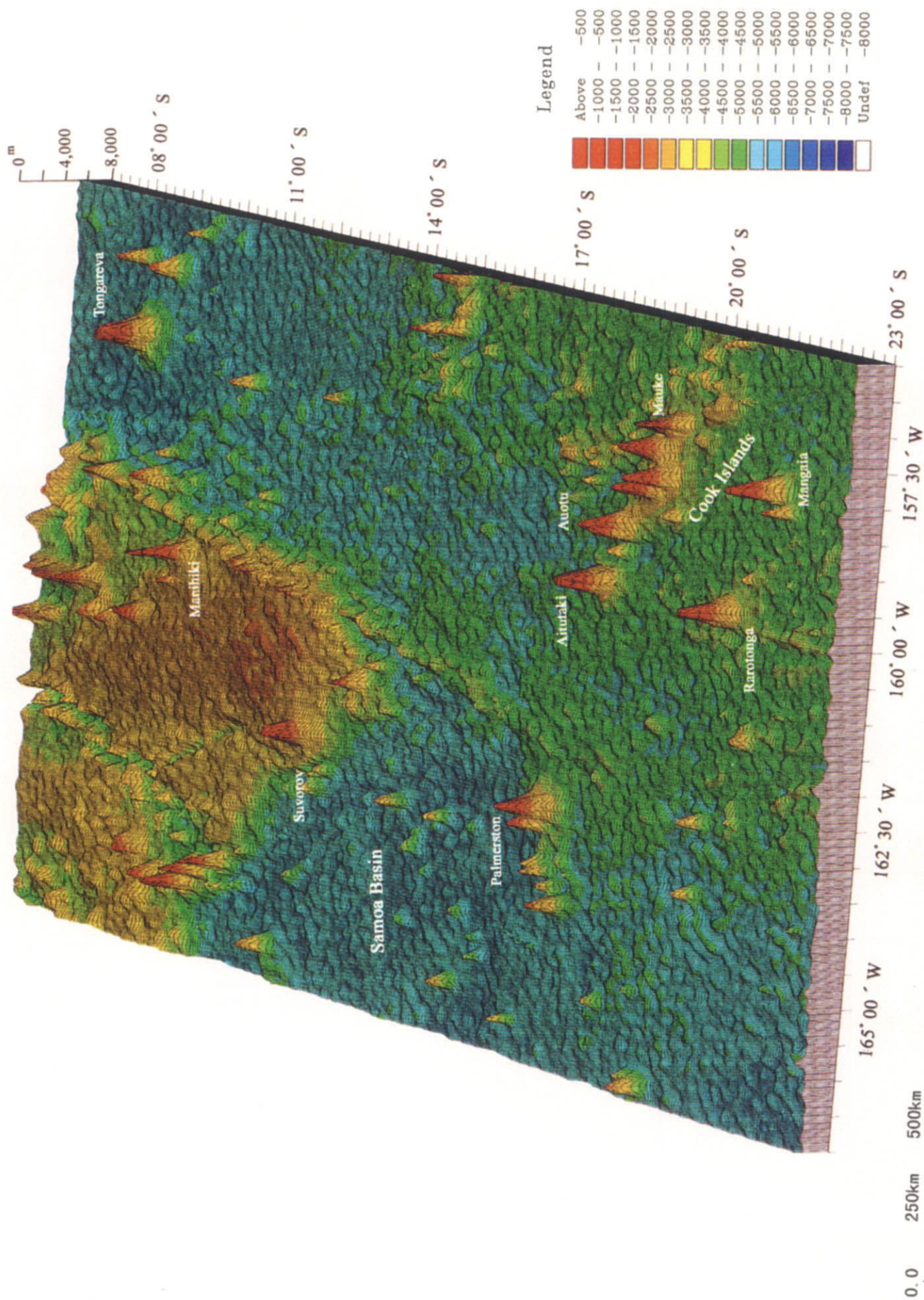


Figure 3-1-2 Bird's Eye View of Bathymetry of Survey Area

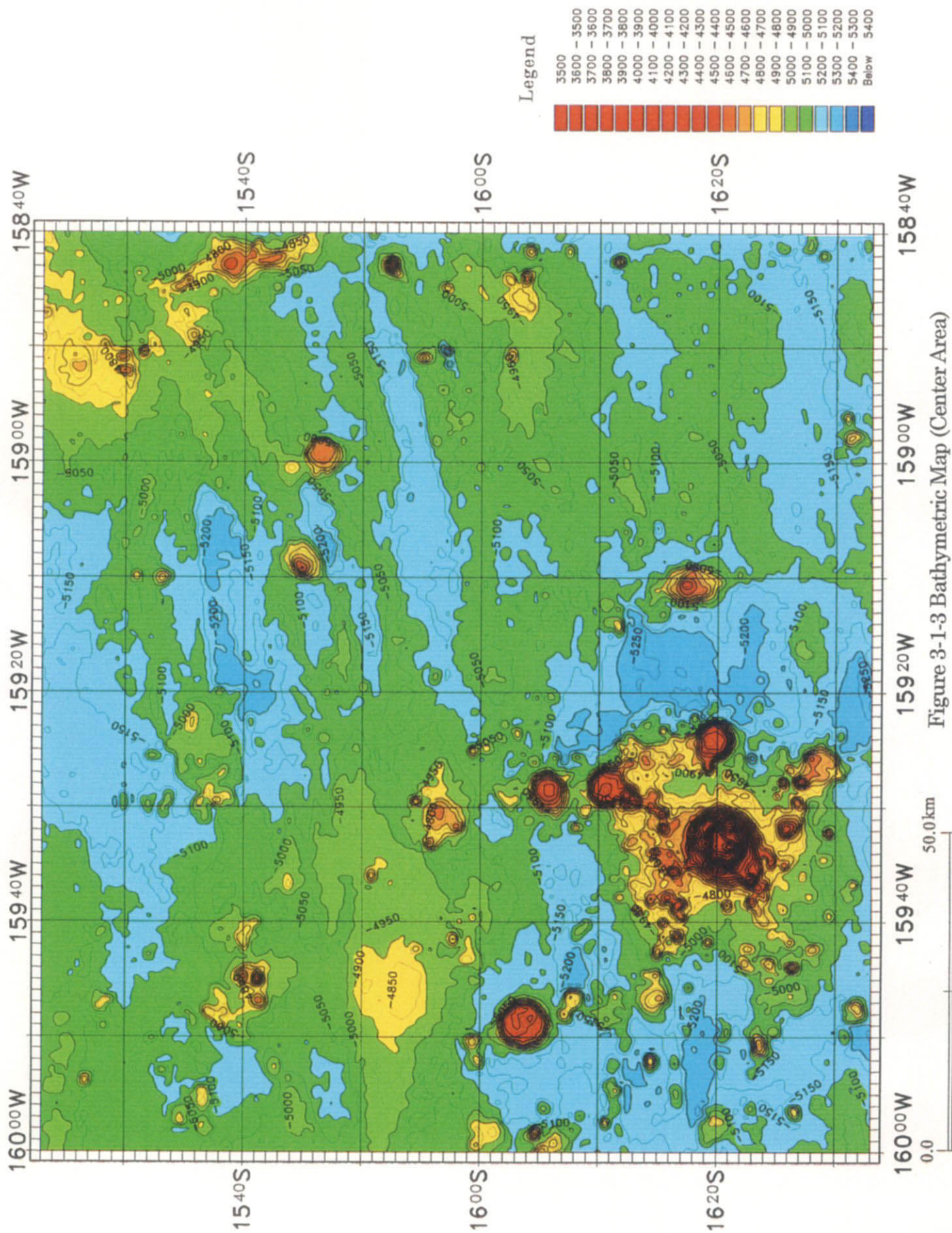


Figure 3-1-3 Bathymetric Map (Center Area)

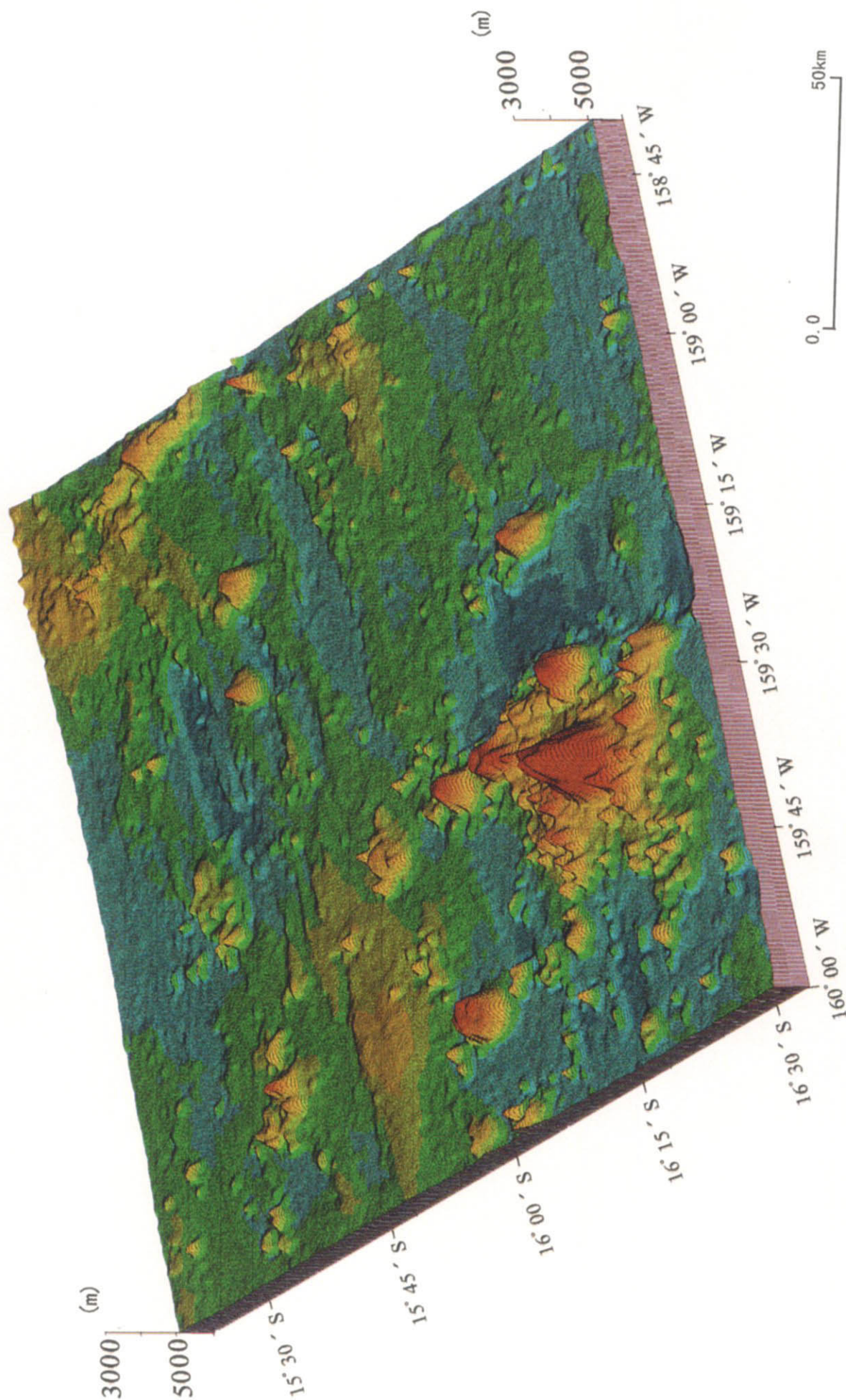


Figure 3-1-4 Bird's Eye View of Bathymetry (Center Area)

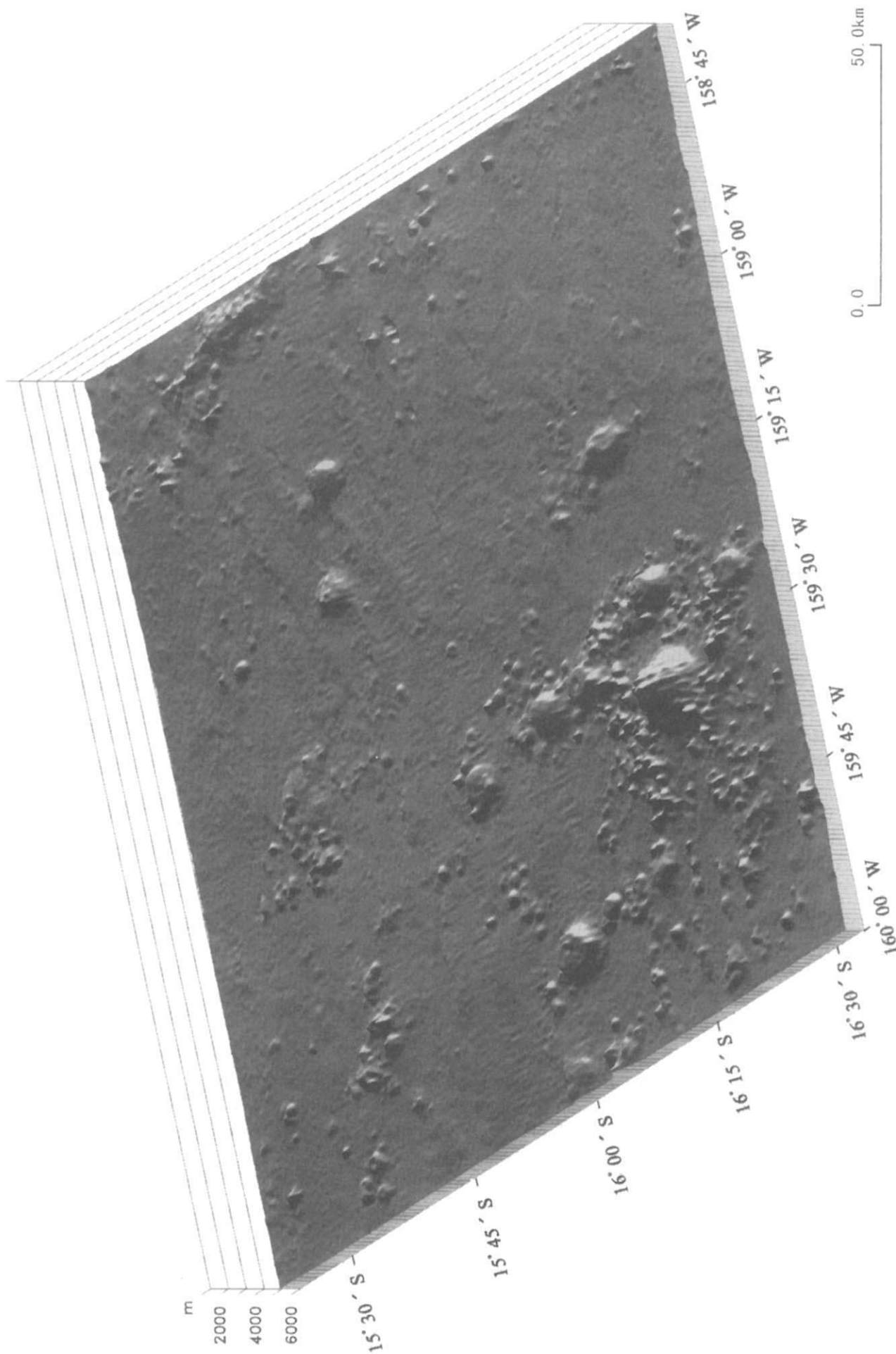


Figure 3-1-5 Bathymetric Shaded Map (Center Area)

This can be observed as a clear lineament in the 3-dimensional shaded map.

<South Area>

Topographic survey was carried out in this area during movement between stations as shown in Attached Figure 2. Thus it is difficult to prepare topographic maps from these data. Therefore, the seafloor topographic map of this area was prepared by compiling ship-borne and satellite data acquired beforehand. The topographic map is shown in Figure 3-1-6 and topographic cross section in Fig. 3-1-7. It is seen from these maps that this area is relatively flat with the Palmerston Island of the Cook Islands to the west and the Aitutaki Island to the east.

The shallow part on the eastern side of the Palmerston Island is classified as hilly zone and the deeper part extending to the northeastern edge from the western side of the Aitutaki Island as flat zone with the boundary shown in Figure 3-1-6.

The hilly zone is an area shallower than 4,800m near the Palmerston with sporadic occurrence of sea knolls of 500~1,000m relative height.

The flat zone is an area deeper than 5,000m with small relief. It gradually deepens northeastward to a maximum of 5,400m. However, many topographic highs of shallower than 4,800m and small sea knolls are observed.

<North Area>

The topographic map of this area (Figure 3-1-8) was prepared by compiling data acquired between stations and satellite data, in a fashion similar to that of the South Area. The topographic cross section is shown as a SBP section together with MBES acoustic intensity map (Fig. 3-2-8). This area is, on the whole, flat with little relief. It is seen from the topographic profile that the seafloor is very flat with hardly any relief to the north of 11° 20'S. In this zone, a prominent seamount with summit depth of 2,290m and relative height of 3,000m is seen at 11° 26'S, 158° 18'E. Some seamounts exceeding 1,000m in relative height and lower knolls, also, occur isolated in the area.

3 - 2 Survey of Surface Sediments

(1) SBP Survey

1) Classification of SBP records

The SBP records of this area are classified as follows. Types with acoustically transparent uppermost layers: a, b, be, el, ts. Types without acoustically transparent uppermost layers: ac, bc, c, d1, d2, ds. Representative records of each type are shown in Figures 3-2-1(1), (2).

① Types with acoustically transparent uppermost layers

• Type a:

This type consists of two layers, namely transparent and opaque layers. The lower opaque layer is strongly and darkly recorded and thus can be distinguished from the upper transparent layer. The thickness of the transparent layer is 10~40m and most of them in this area is less than 20m thick.

• Type b:

Basically this type consists of transparent and opaque layers similar to Type a,

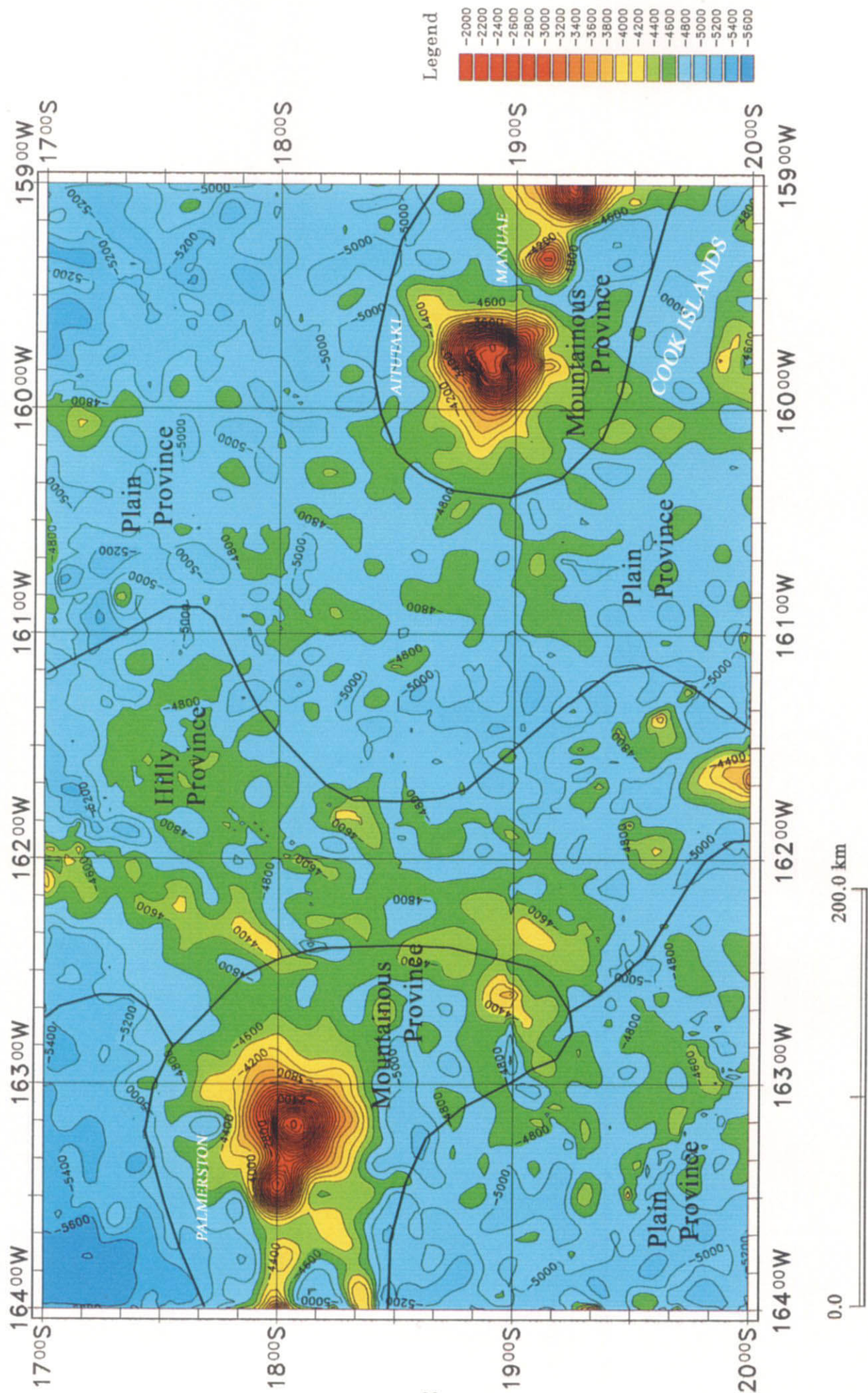


Figure 3-1-6 Bathymetric Map (South Area)

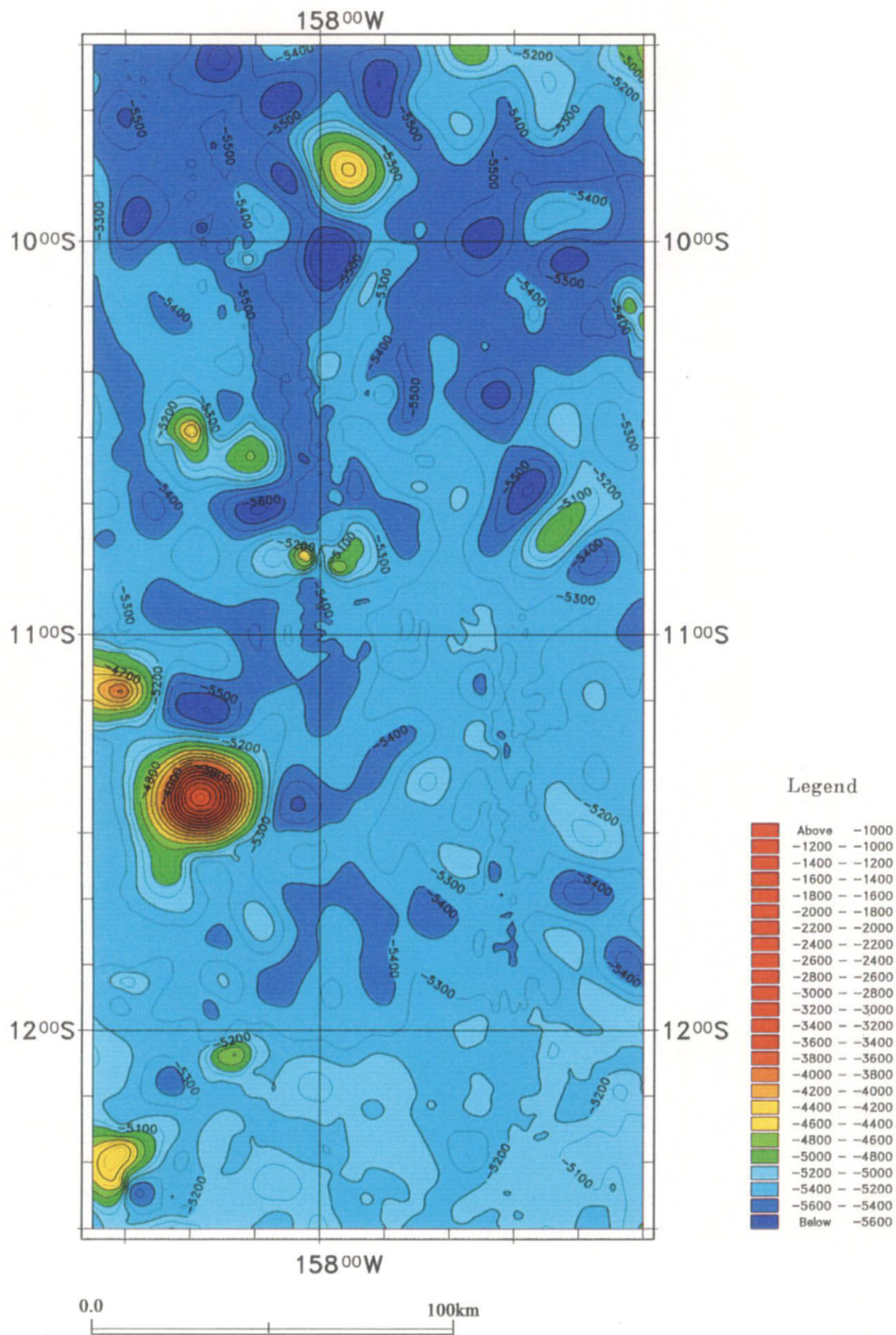
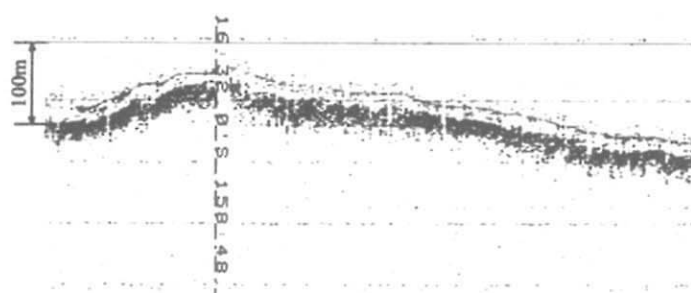


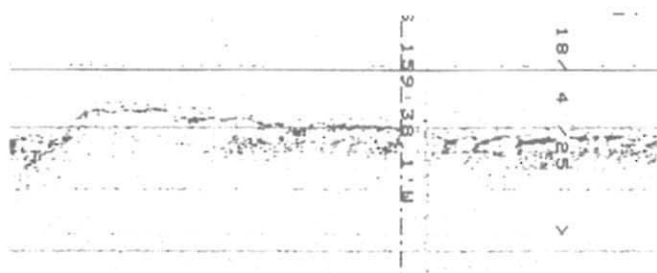
Figure 3-1-8 Bathymetry Map (North Area)



Type a

Line 632-0

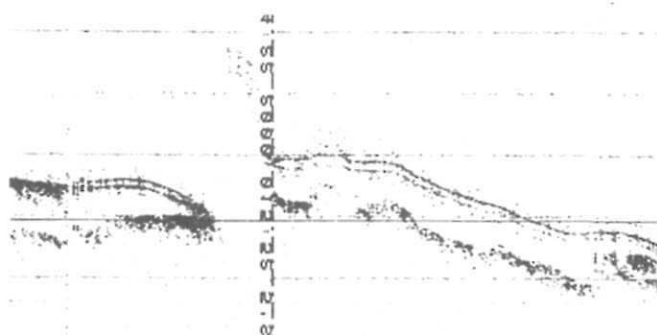
16° 32' S • 158° 50' W



Type b

Line 524-0

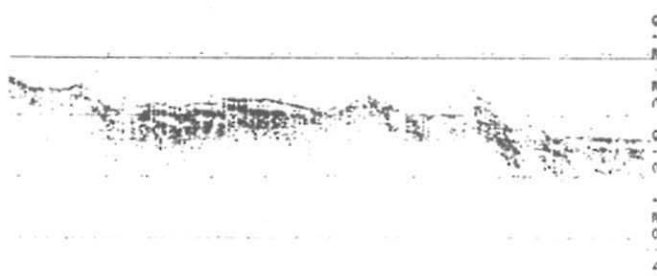
15° 24' S • 159° 40' W



Type be

Line 552-1

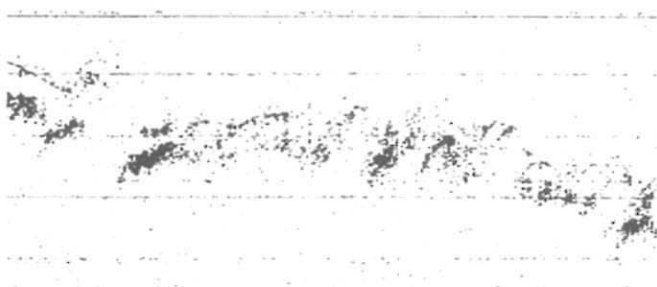
15° 52' S • 159° 35' W



Type e1

Line 556-0

15° 56' S • 158° 37' W



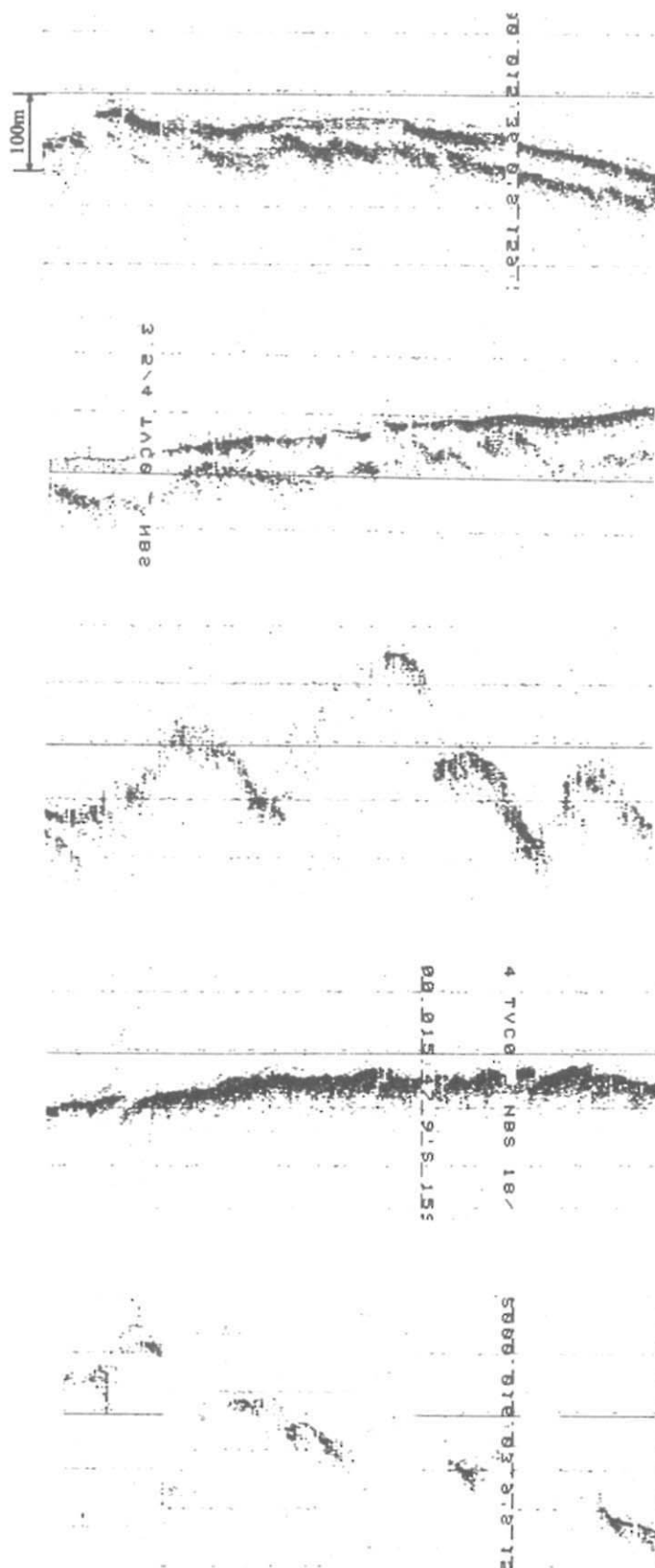
Type ts

Line 540-0

15° 40' S • 159° 25' W

Figure 3-2-1 Classification of SBP Profiles (1)

Types with uppermost acoustic transparent layer



Type ac
Line 536-1
15° 36' S • 159° 35' W

Type bc
Line 552-1
15° 52' S • 159° 50' W

Type d1
Line 604-1
16° 04' S • 159° 30' W

Type d2
Line 548-1
15° 48' S • 159° 50' W

Type ds
Line 604-0
16° 04' S • 158° 45' W

Figure 3-2-1 Classification of SBP Profiles (2)

Types without uppermost acoustic transparent layer

but the lower opaque layer is not always clearly confirmed. The thickness of the transparent layer is 10~60m.

- Type be:

This type consists of two layers, namely transparent and opaque, but thin opaque layers are intercalated in the uppermost part of the transparent layer. The thickness to the upper opaque layer is 5~10m and 50~60m to the lower opaque layer.

- Type el:

The upper part of this type consists of alternation of transparent and opaque layers. This type occurs infrequently in this area.

- Type ts:

Transparent layer is seen in the uppermost part, but the records and the boundary to the opaque layer are not clear because of acoustic scattering by topographic relief.

② Types with acoustically opaque uppermost layer

- Type ac:

This type appears to consist of transparent-opaque layers as in the case of Type a and the boundary with the lower opaque layer is clear. However the uppermost part of the upper layer, namely the seafloor surface, is not a single line, but an opaque layer of about 10m thick. This type is transitional from Type d2, which will be mentioned later, and the upper transparent layer was treated as 0m.

- Type bc:

This type appears to be similar to Type b with transparent-opaque layers. But the thickness to the opaque layer exceeds 50m and the boundary of many records is not clear. The seafloor surface is not recorded as one line as in the case of Type ac, but is about 10m thick opaque layer. The thickness of the upper transparent layer was also treated as 0m.

- Type c:

This type consists of 3 layers, namely opaque-transparent-opaque layers. This type is almost non-existent in the Center Area, but many are observed in the South Area.

- Type d1:

This type is composed only of opaque layers. It is inferred to indicate exposed rocks and the distribution generally agrees with that of seamounts and sea knolls.

- Type d2:

This type consists only of opaque layers similar to Type d1. But this type occurs in topographically flat areas and not on seamounts and sea knolls. This generally is correlated to coarser surface sediments and consolidated sediments.

- Type ds:

This type appears to consist only of opaque layers, but the records are not clear because of scattering of waves by seafloor relief.

2) Distribution of SBP types

The various types of SBP records and the topography of this sea area are harmonious. Namely Types a and b records which indicate the occurrence of surface sediments are distributed mainly in topographically flat areas, whereas Types d1, d2

which indicate occurrence of opaque layers are distributed on seamounts, sea knolls and topographic highs.

<Center Area>

The distribution of SBP record types in the Center Area is shown in Figure 3-2-2, and isopach maps in Figure 3-2-3. The record types observed in this area will be mentioned below.

- Type a:

This type occurs mainly in flat areas and near sea knolls. In this area, it occurs extensively in the flat zone between the two sea-knoll chains at the southwestern end and northeastern end of the area. The seafloor surface is relatively smooth, and it is inferred to be covered almost evenly by unconsolidated sediments. The thickness is mostly less than 20m and rarely exceeds 40m.

- Type b

This type is generally observed in flat zones, but in somewhat rough surface parts compared to Type a. In this area, it occurs more or less concentrated in the northern end and also at the boundary between Type a and Type d2 to the east. It also occurs locally within Type a. The thickness is 20~50m.

- Type be

This type is observed locally at 15° 52'S, 159° 30'W and the transition zone from the flat zone in the south end to topographic high. The seafloor is very smooth and the thickness of the layer appears to be constant throughout. The uppermost layer is about 10m thick.

- Type d1

The distribution of this type coincides with that of the exposed rocks in this area, and it is seen in seamounts and sea knolls in various localities. It is particularly predominant in the seamounts and knolls of the southwestern end of the area.

- Type d2

This type occurs at the transition zones from seamounts and knolls to flat plains, and at relatively flat zones of topographic highs in the southwestern and northeastern parts of the area. This is a very common type next to Type a. This type is inferred to indicate areas almost totally without unconsolidated sediments, and the seafloor probably consists of exposed rocks or is covered by consolidated sediments or crust-like materials.

<South Area>

This area was investigated in 1990 and SBP survey was then carried out. Subsequently, however, SBP equipment was vastly improved and the mechanism of the generation of acoustic waves changed. Therefore the SBP records of the same locality often differ between the previous and present surveys. Since it is difficult to compile these two types of records, the SBP records acquired from the present survey are shown overlapping those of the 1990 survey as in Figure 3-2-4.

It is seen from Figure 3-2-3 that surface sediments are not developed in this area because Types c and ds records indicating opaque layers are predominant. This is inferred to be closely related to the fact that this area is topographically included in the Southern Cook Islands. Type c is distributed in the southern and Type ds in the

northern part of this area.

<North Area>

The distribution of the SBP record types in this area is shown in Figure 3-2-5. The distribution of SBP record types change to the north and south of 11° S. Namely on the northern side of 11° S, the seafloor is very flat and corresponding Type d2 records occur evenly throughout. Whereas on the southern side, the topographic relief is large and Type a records indicating transparent layers and Type bc and d2 corresponding to opaque layer occur alternately.

(2) MBES acoustic intensity distribution

Seafloor acoustic reflection intensity by MBES generally shows the extent of exposed rocks or unconsolidated sediments. Exposed rocks reflect acoustic waves with high intensity and is expressed as dark-colored parts (black) in acoustic reflection intensity images. On the other hand, low acoustic reflection intensity from unconsolidated sediments is expressed as pale-colored parts (white), and the intensity varies by the grain size, compaction, and other relevant factors. Distribution of solid material such as manganese nodules on unconsolidated sediments is shown in intermediate color tone (gray) in the images.

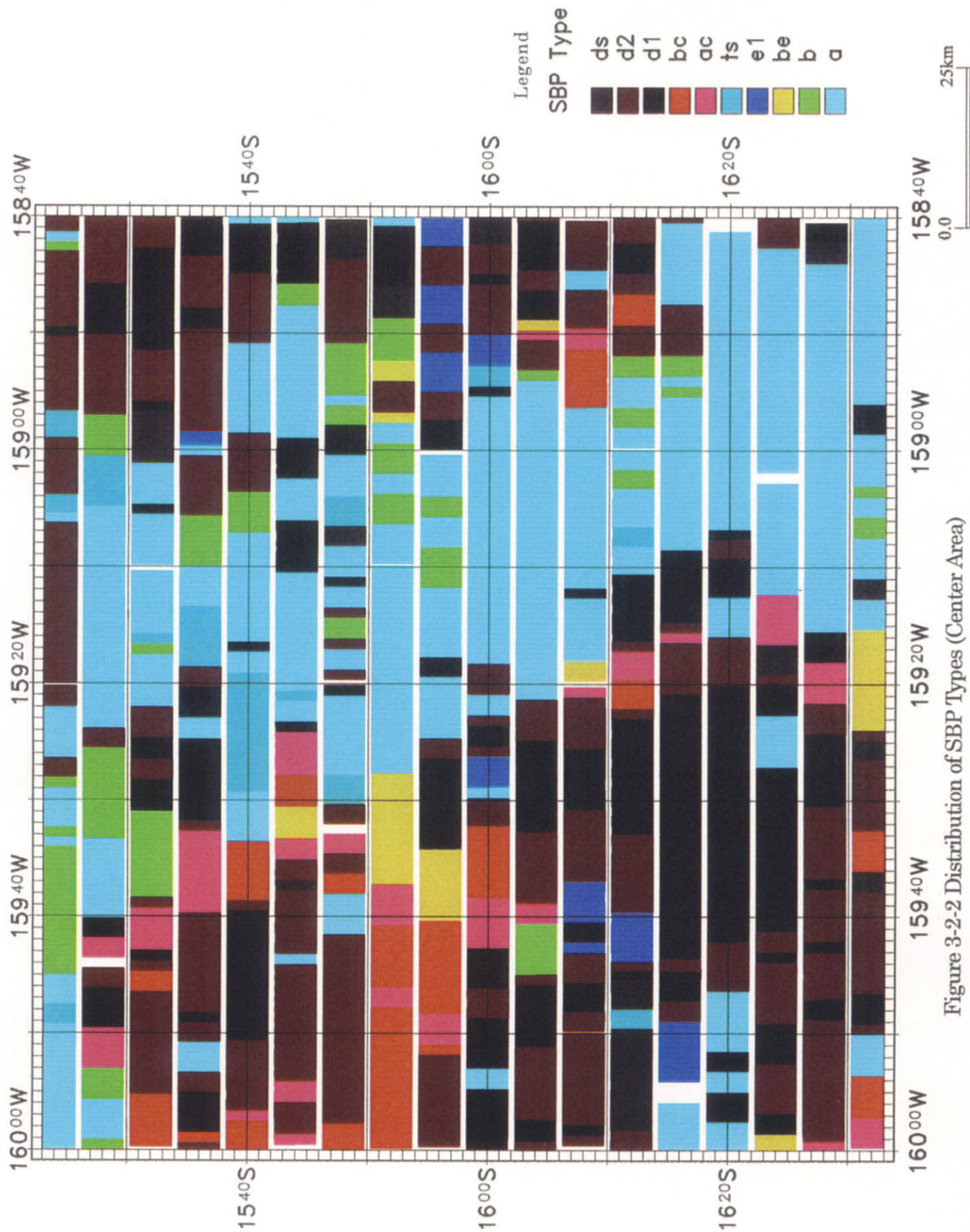
The acoustic reflection intensity distribution of the survey area generally shows these patterns mentioned above and is harmonious with the results of the SBP survey. Namely MBES images have pale tone indicating low acoustic intensity at localities where the existence of unconsolidated sediments was confirmed by SBP and the images show darker color tone at localities where exposed rocks or crusts occur. Characteristics of MBES acoustic reflection intensity distribution is given below.

<Center Area>

Acoustic reflection intensity distribution in the Center Area is shown in Figure 3-2-6. The distribution is harmonious with the SBP types, and is largely divided into pale image parts and dark image parts. The former indicates flat plain zone in the central part corresponding to SBP Types a and b. In this part, MBES acoustic reflection from the seafloor is weak indicating the unconsolidated bottom sediments such as clay and ooze and the image tone becomes pale (white) southward and SBP results also show that acoustically transparent layer thickens and the area has topographically low relief.

On the other hand, the dark image zones are found to correspond to seamounts and knolls. These parts also extend on both sides of the pale-colored flat plain in the central part. Here it is somewhat topographically high, but is more or less flat. Thus although these are not zones of rock exposures, but are inferred to be zones without unconsolidated sediments. The sediments would be extremely thin if any exist.

In the basins of the southwestern part, intermediate color tone (between pale and dark colors) parts are observed surrounding seamounts in the image. This is a topographically deep zone where unconsolidated sediments are expected. But SBP Types ac and bc are distributed indicating the deposition of consolidated or coarse-grained sediments.



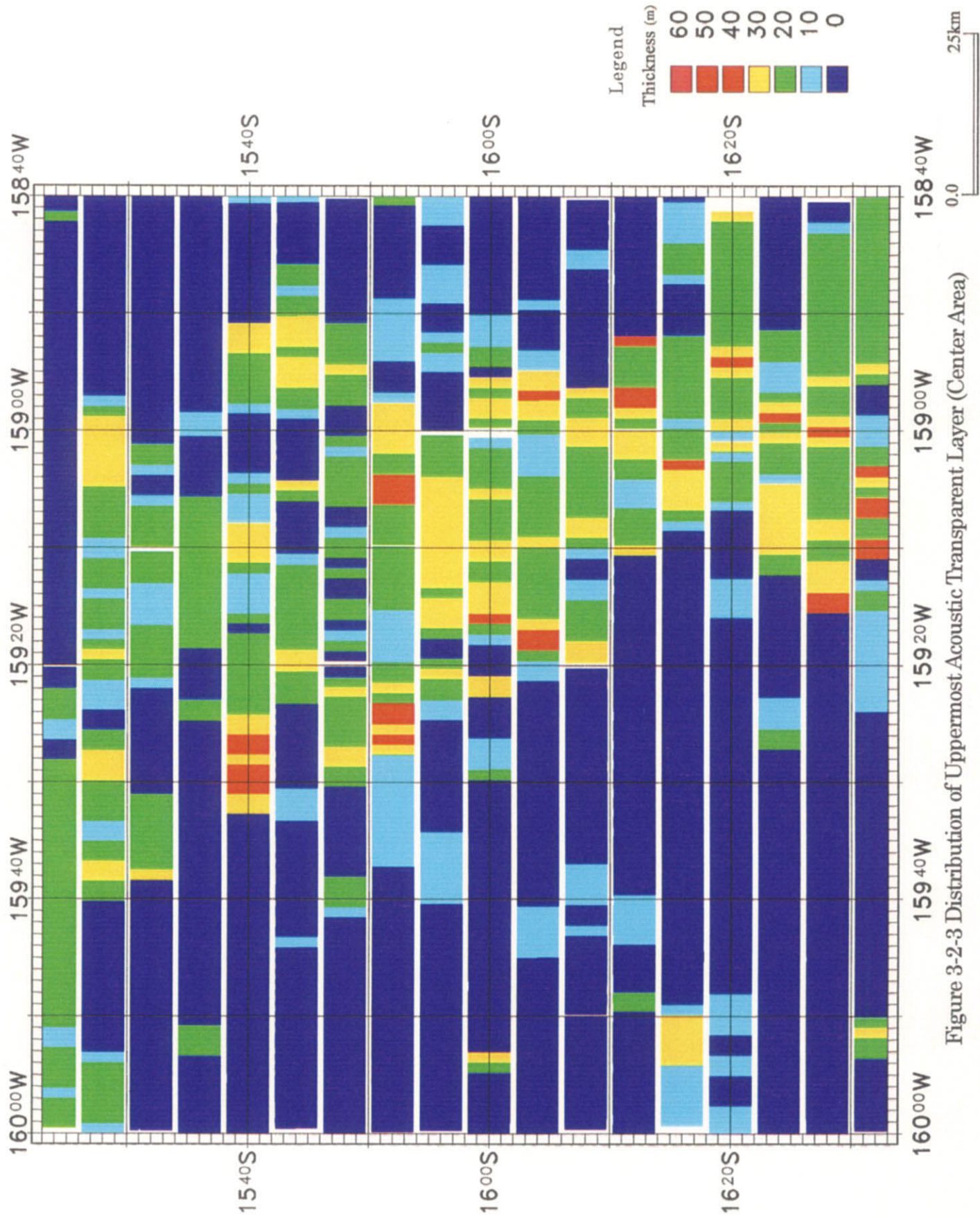


Figure 3-2-3 Distribution of Uppermost Acoustic Transparent Layer (Center Area)

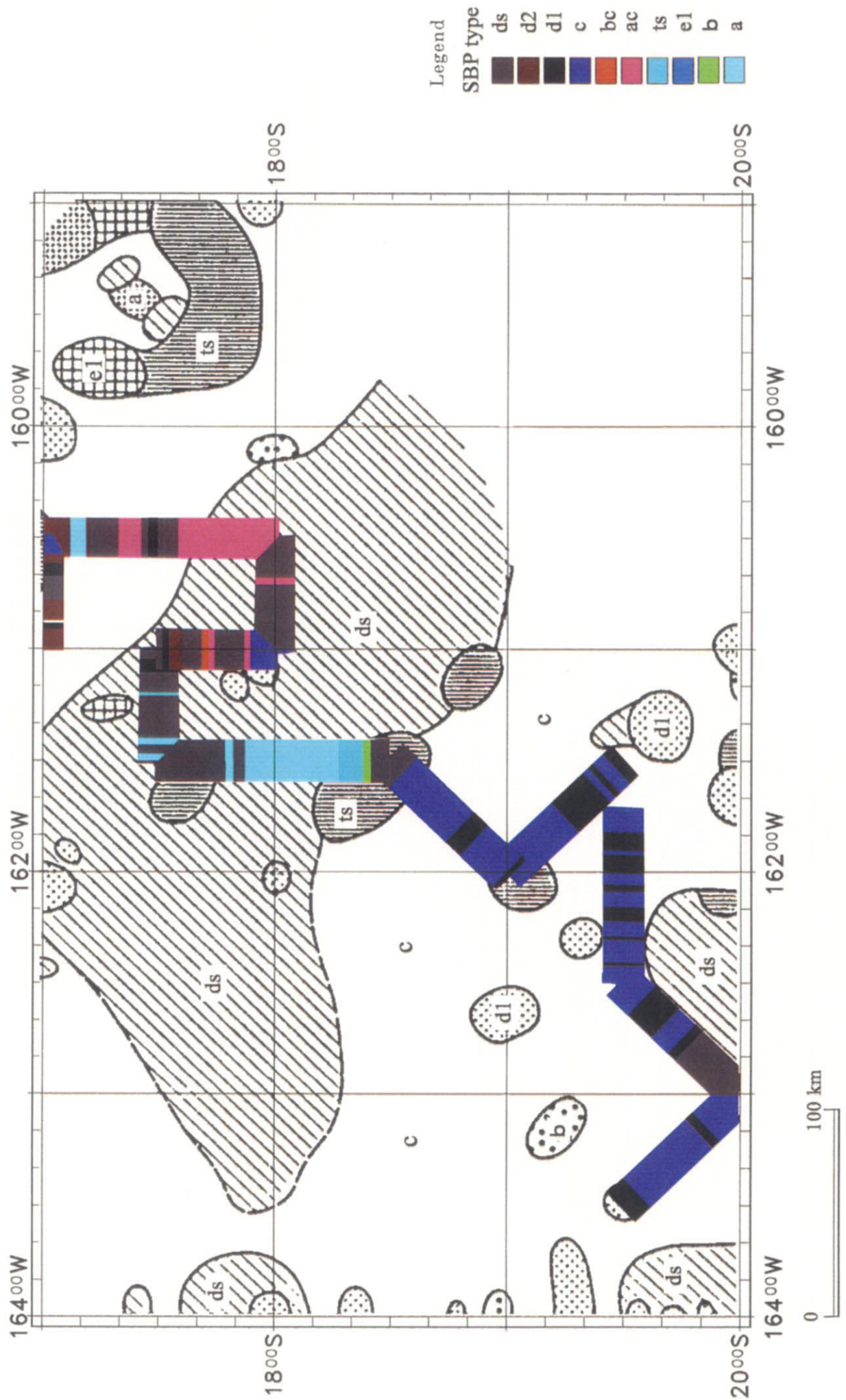


Figure 3-2-4 Distribution of SBP types (South Area)

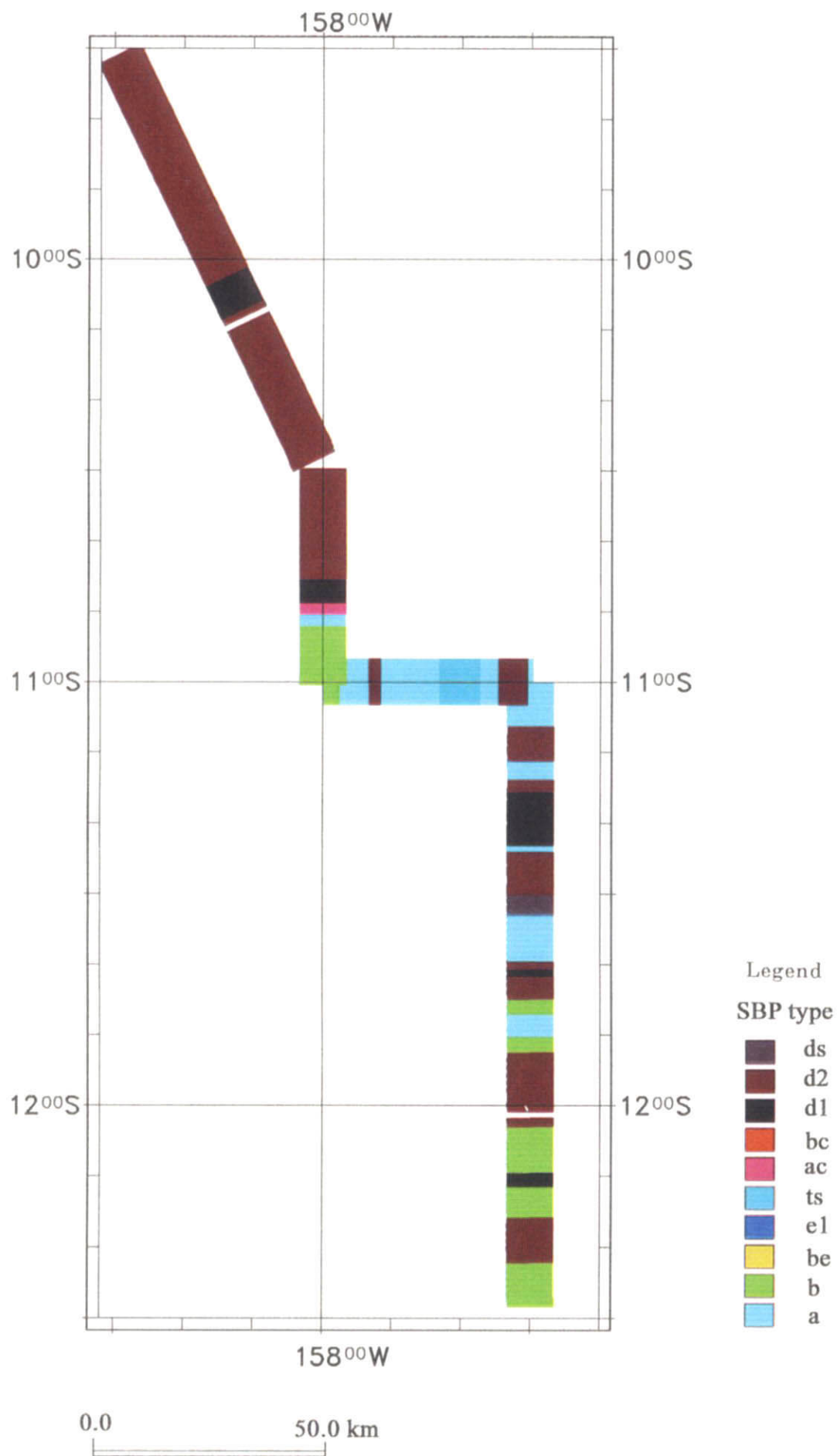


Figure 3-2-5 Distribution of SBP types (North Area)

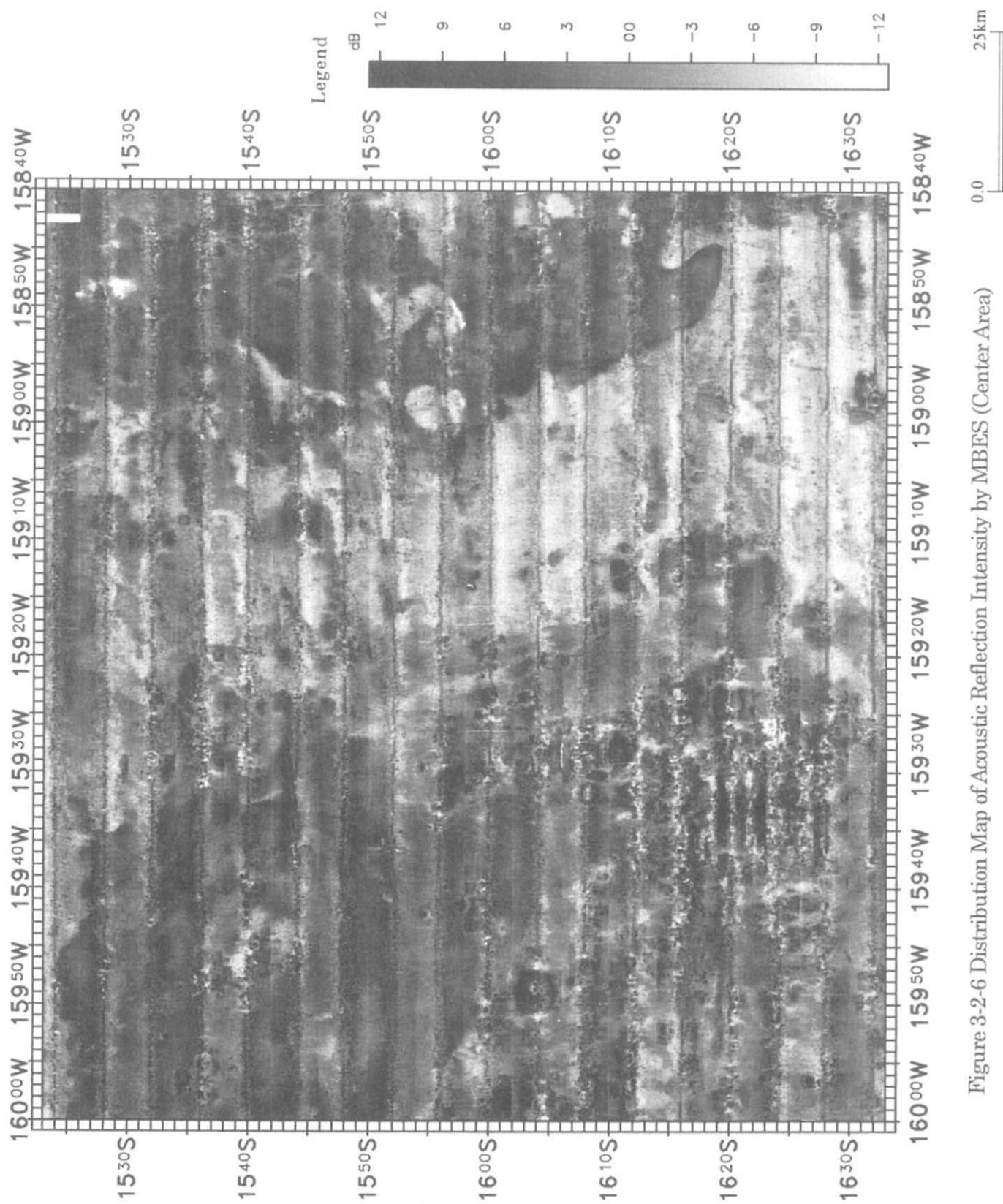


Figure 3-2-6 Distribution Map of Acoustic Reflection Intensity by MBES (Center Area)

<South Area>

During the previous surveys of this area, MBES method was not yet introduced. Thus topographic survey was made by NBS or PDR. Therefore MBES acoustic reflection intensity data were acquired for the first time in this area by the present survey. The acoustic reflection intensity map for the track lines is shown in Figure 3-2-7.

Unconsolidated sediments are not developed throughout this area and SBP acoustically transparent upper layers are not observed. Thus MBES average reflection intensity tends to be higher and Type d1 records, corresponding to topography, have dark color tone at seamounts and knolls. The SBP Types c and ac of this area, however, have somewhat lower level of reflection intensity compared to the Center Area and thus the acoustic intensity images in these localities are expressed in paler tone than in the Center Area. This is inferred to indicate the existence of small amounts of unconsolidated sediments not detectable by SBP Types c and ac, thus lowering the MBES reflection intensity.

<North Area>

This is the first survey of this area, and acoustic intensity map was prepared only from the MBES acoustic reflection intensity data measured during movement between stations. The map is shown in Figure 3-2-8. Profiles of the SBP records are also shown in this map. It is seen from this map that to the south of 11° N, topographic relief is high and correspondingly dark and pale MBES acoustic reflection intensity image color tones alternate in this zone. On the other hand to the north of this parallel, the topography becomes very flat and the image has pale color tone with the exception of seamounts in parts of the zone. Particularly to the north of 10° 30'N, the image is evenly pale throughout the zone indicating extremely smooth seafloor topography.

3 - 3 Deep-sea Sediments

Unconsolidated sediments samples were collected at 90 sampling sites by FG, SC, and LC.

With FG, deep-sea sediments on the surface were sampled by mud-sampler attached to the grab. Using SC undisturbed columnar cores of around 40cm deep were collected. Furthermore, LC sampling was carried out at eight localities and columnar samples were collected. Grain size, color tone, reaction to hydrochloric acid and hydrogen peroxide, and other relevant properties of the collected samples were examined, and their smear slides were studied microscopically. Contained fossils were identified and chemical analysis was carried out for SC and LC samples.

(1) Classification of Deep-sea Sediments

Smear slides amounting to 135 were prepared from deep-sea sediments collected from 90 localities and they were studied microscopically. The content of the terrigenous and volcanogenic clastic grains was all less than 25% in these unconsolidated deep-sea sediments. Thus they are all pelagic in nature and were classified in accordance with the standard below.

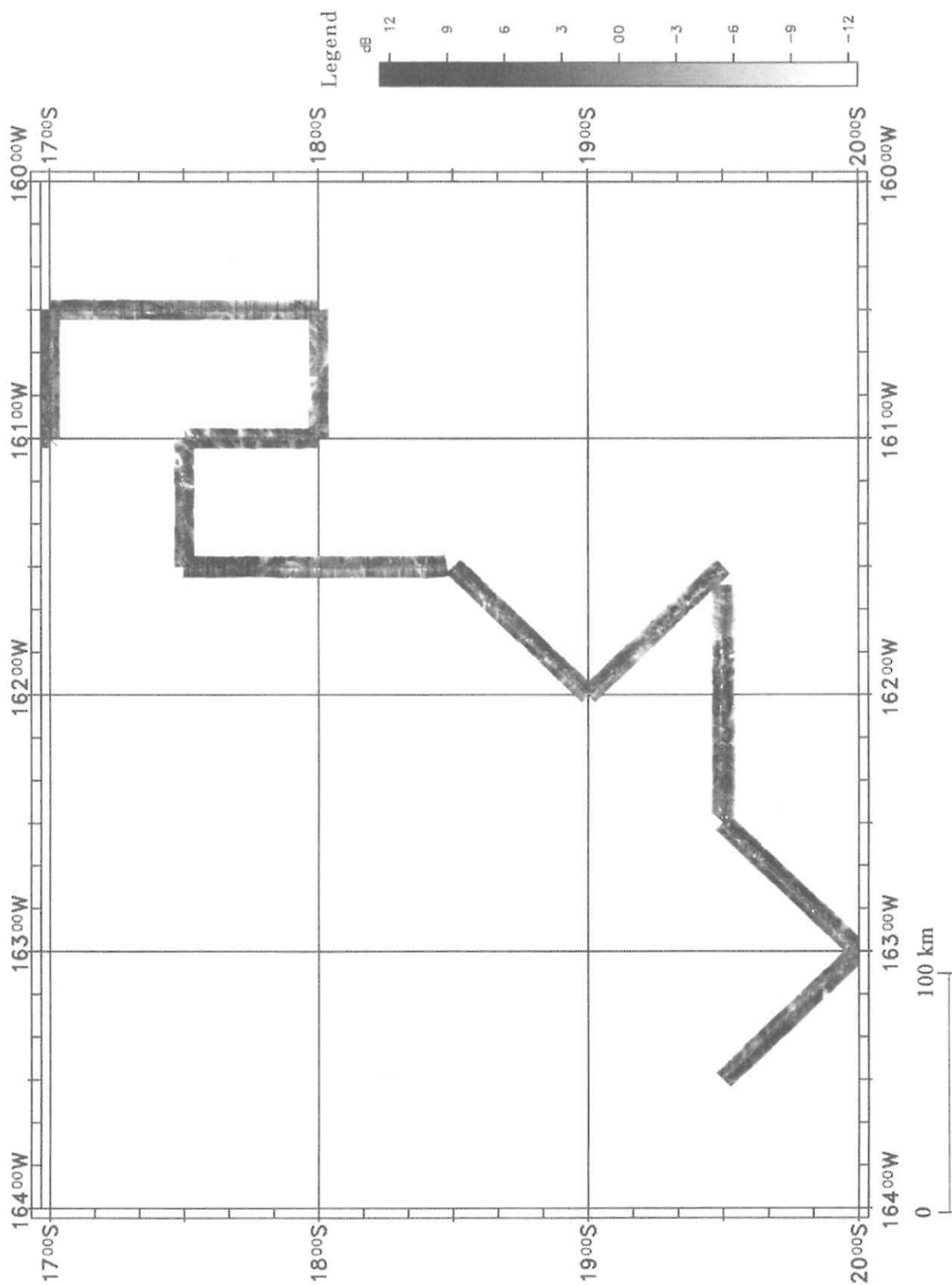


Figure 3-2-7 Distribution Map of Acoustic Reflection Intensity by MBES (South Area)

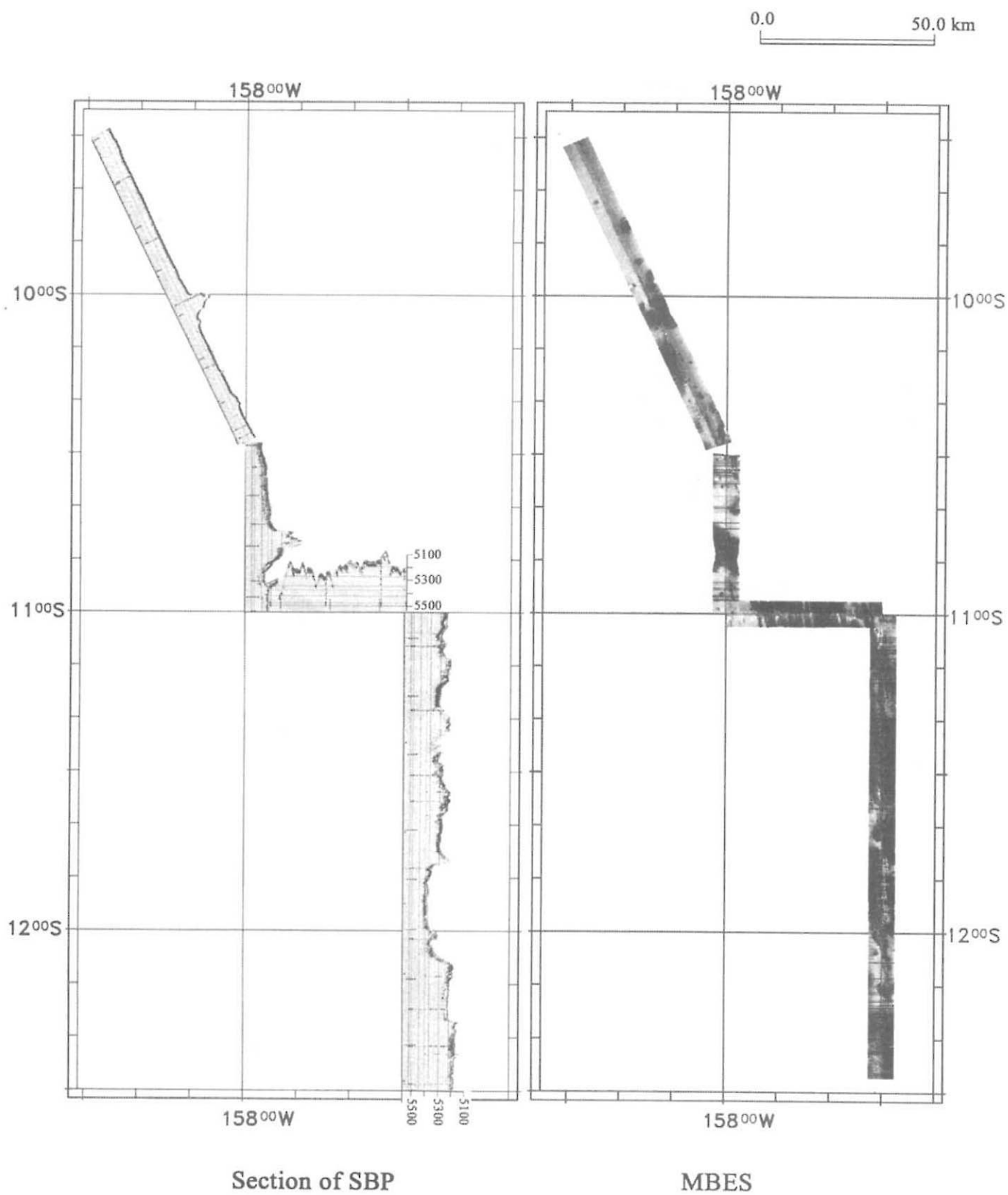


Figure 3-2-8 Distribution Map of Acoustic Reflection Intensity by MBES (North Area)

Table 3-3-1 Classification Standard of Deep-sea Sediments

	Total Fossil (%)	*1 Siliceous Fossil(%)	*2 Calcareous Fossil (%)	Remarks
Brown clay	<10			Impermeable Contains zeolite minelas more than 5~10%
Insoluble brown clay	<10			
Zeolitic clay	<10			
Siliceous clay	10~30		< 5	Siliceous fossil > Calcareous fossil Calcareous fossil > Siliceous fossil
Silic-calcareous clay	10~30		> 5	
Calc-siliceous clay	10~30	> 5		
Calcareous clay	10~30	< 5		
Foraminifera ooze	>30			Calcareous fossil > Siliceous fossil Mainly foraminifera fossil Calcareous fossil > Siliceous fossil Mainly coccolith Siliceous fossil > Calcareous fossil
Coccolith ooze	>30			
Silic-calcareous ooze	>30		< 5	
Siliceous ooze	>30		> 5	

* 1 Radiolaria, Diatom, Silicoflagellate, Sponge spicule

* 2 Foraminifera, Calcareous nannoplankton

(2) Properties of Deep-sea Sediments

These deep-sea sediments are classified as shown in Table 3-3-2 on the basis of microscopic examination of smear slides. Smear slides of sediments below the surface were also prepared for LC and SC samples, but samples near the surface were used as representing the sampling points. Samples collected this year generally contained smaller amounts of organic remains, and ooze containing organic remains in amounts exceeding 30% were not found. There were two calcareous clay samples containing about 15% of foraminifera remains, and others were all brown clay. Some of the brown clay is not soluble. Siliceous remains of radiolaria occur in almost all samples, but the content is less than 1%.

Table 3-3-2 Type of Deep-sea Sediments Collected by Sampling

	South Area		Center Area		North Area		Total	
	Number s	Ratio (%)	Numbers	Ratio (%)	Numbers	Ratio (%)	Number s	Ratio (%)
Brown clay	5	42	64	96	11	100	80	89
Insoluble brown clay	6	50	2	3	0	0	8	9
Calcareous clay	1	8	1	1	0	0	2	2
Clay with Foraminifera fossil	11	92	19	28	0	0	30	33
Clay without Foraminifera fossil	1	8	48	72	11	100	60	67
Total	12	100	67	100	100	100	90	100

The characteristics of the deep-sea sediments are as follows.

1) Brown clay

Almost all brown clay has dark reddish brown color and dark brownish red clay is found rarely. Almost all have 5YR3/2 tone of Munsell Soil Color Charts, and those with 5YR3/3, 2.5YR3/2, and 2.5YR3/4 tone occur rarely.

The main constituents of this clay are: clay minerals, siliceous organic remains, and calcareous organic remains. It also includes minor amounts of amorphous material, volcano clastics, zeolites, barite, ichthyolith, and micro-nodules (iron-manganese oxides).

The siliceous organic remains are radiolaria and sponge spicules and they occur in almost all samples in small amounts of less than 1%. Calcareous organic remains consist of foraminifera and coccolith. Foraminifera occur in about a third of the samples and mostly in amounts less than 1% with some exceptions reaching 5%. Coccolith occurs in about half of the samples and the content is all less than 1%.

Micro-nodules occur in almost all samples, and most of them have minute grain size and the content is mostly less than 1% with exceptions reaching several percent.

Brown clay consists mostly of minute clay particles but some include silt-fine sand. The sand consists of micro-nodules and somewhat solidified mud.

2) Insoluble brown clay

Insoluble brown clay has mineral composition similar to brown clay, but it has strong adhesiveness and does not disperse in water easily. Cohesion of clay particles is observed microscopically and is aggregates of these cohesion grains.

The color of this clay is dark reddish brown similar to brown clay or somewhat darker and is 5YR3/2, 5YR3/3, and YR2.5/2 of Munsell Soil Color Charts.

The micro-nodules of this clay are slightly coarser than those of brown clay and occupy about 1% and are more oxidized.

3) Calcareous clay

Samples containing more than 10% organic remains were collected at only two localities, and they contain about 15% of calcareous remains. The color is dark yellowish brown to dark reddish brown and is 10YR4/4 and 5YR3/2 of the Munsell Soil Color Charts.

The contents are about 15% foraminifera and calcite with 1% coccolith. In addition to them, small amounts of radiolaria, spicules, and micro-nodules are found.

(3) LC and SC Sampling of Deep-sea Sediments

LC sampling was attempted at eight localities in order to determine the variation of deep-sea sediments with depth and the occurrence of buried manganese nodules and samples were collected at seven points. Columnar sections of the each LC sample are laid out in Attached Figure 4 and columnar sections of the area in Figure 3-3-1.

The color of the clay is dominantly dark brown (5YR3/2). This clay is divided into brown clay and insoluble brown clay by smear slide observation. Brown clay occurs in higher horizon than the insoluble clay in Samples 00S1138LC01 and 00S16436LC34, but the relation is reverse in 00S1736LC25. 00S1636LC50 consists generally of insoluble clay.

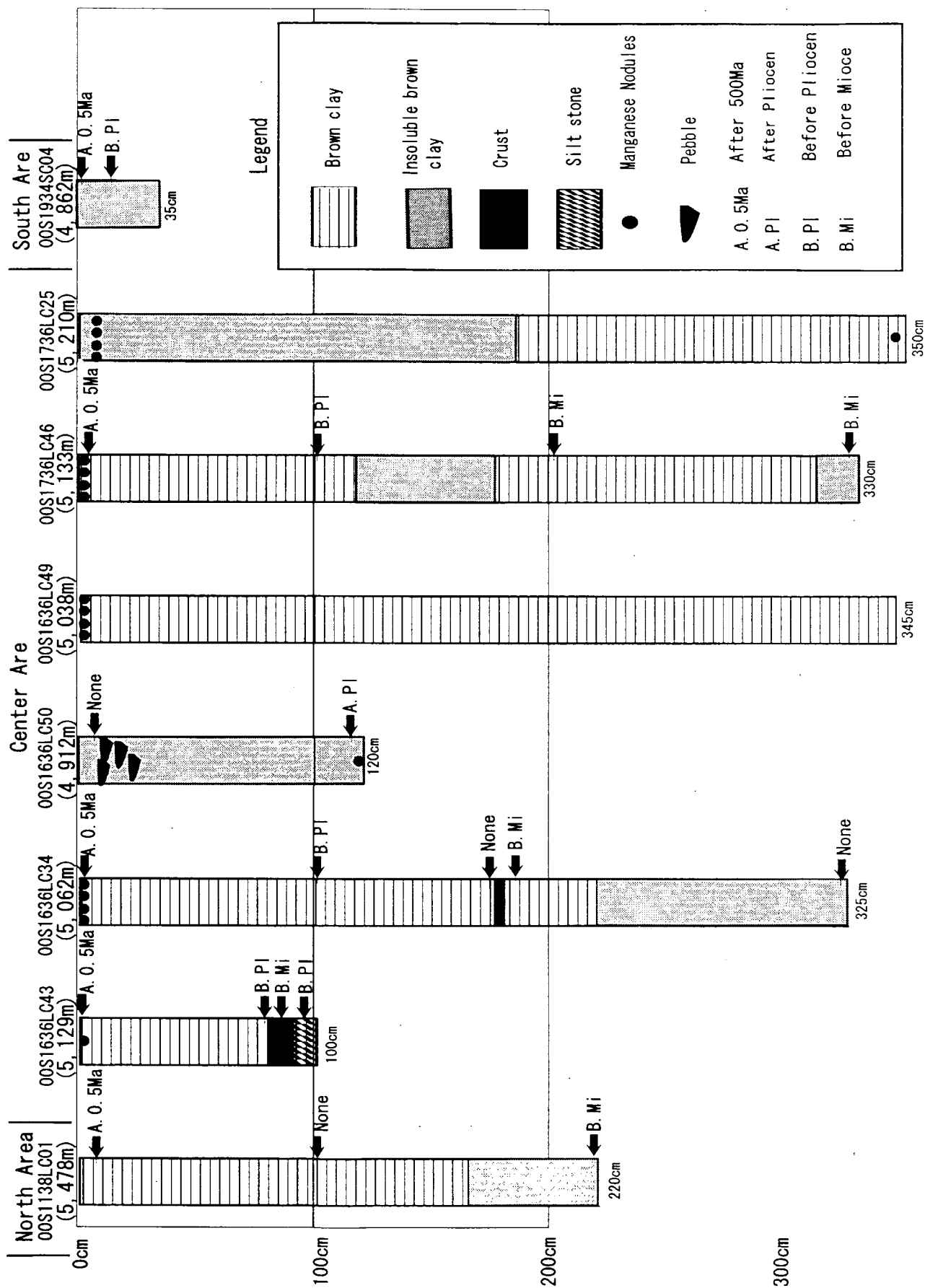


Figure 3-3-1 Columnar Charts of LC Core

Manganese nodules were collected at the surface of 5 holes. They were not found in 00S1138LC01 and pebbles containing crusts and crust fragments were collected at 00S1636LC50. Manganese nodules were found in the deepest parts, namely near 120cm of 00S1636LC50 and near 350cm of 00S1736LC25 and these are possibly buried manganese nodules.

Crusts were observed in 00S1636LC43 and 00S1636LC34. Crusts with 20mm average thickness occur at 85cm depth with mudstone attached directly below the crust in the former hole. In the latter hole, 5mm thick crusts were found between brown clay at 177cm depth.

By SC sampling, 25~40cm thick unconsolidated sediments were found in five localities. Columnar sections are shown in Attached Figure 5. They are dark brown (5YR3/2) clay and smear slide studies showed that they are all brown clay with the exception of 00S1934SC04, which consists of insoluble clay.

(4) CCD (Carbonate Compensation Depth)

The relation between the carbonate content of deep-sea sediments and water depth is shown in Figure 3-3-2. The carbonate content was inferred from the contents of the remains of foraminifera and other calcareous organisms and of calcite of unknown origin. These values were determined from microscopic observation of smear slides. The water depth of the sampling points increased from the South to Center to North Area while the carbonate contents of the samples tended to decrease. Furthermore, some samples from zones shallower than 5,050m contain carbonates up to 5%, but those from zones deeper than the above contain 0% or less than 1% carbonate. Thus the CCD in the present survey sea areas is inferred to exist near 5,050m of water depth.

(5) Distribution of Deep-sea Sediments

The distribution of deep-sea sediments of the three areas surveyed during the present year was examined including the data from the past surveys. These sediments are mostly brown clay and the calcareous sediments (calc-siliceous clay and calcareous clay) occur sporadically near seamounts and sea knolls in relatively shallow zones.

<Center Area>

FG, SC, and LC sampling were carried out at a total of 129 points of the Center Area during the past and the present survey, and deep-sea sediments were collected at 108 points. The ratio of the sediments collected is laid out in Table 3-3-3 and the distribution of the deep-sea sediments in Figure 3-3-3.

The deep-sea sediments of this area are mostly brown clay and these are distributed in most of the area. Calcareous sediments occur sporadically in relatively shallow zones such as seamounts and sea knolls. Insoluble brown clay was collected at only two points, and they also tend to occur in relatively shallow zones such as seamounts and sea knolls.

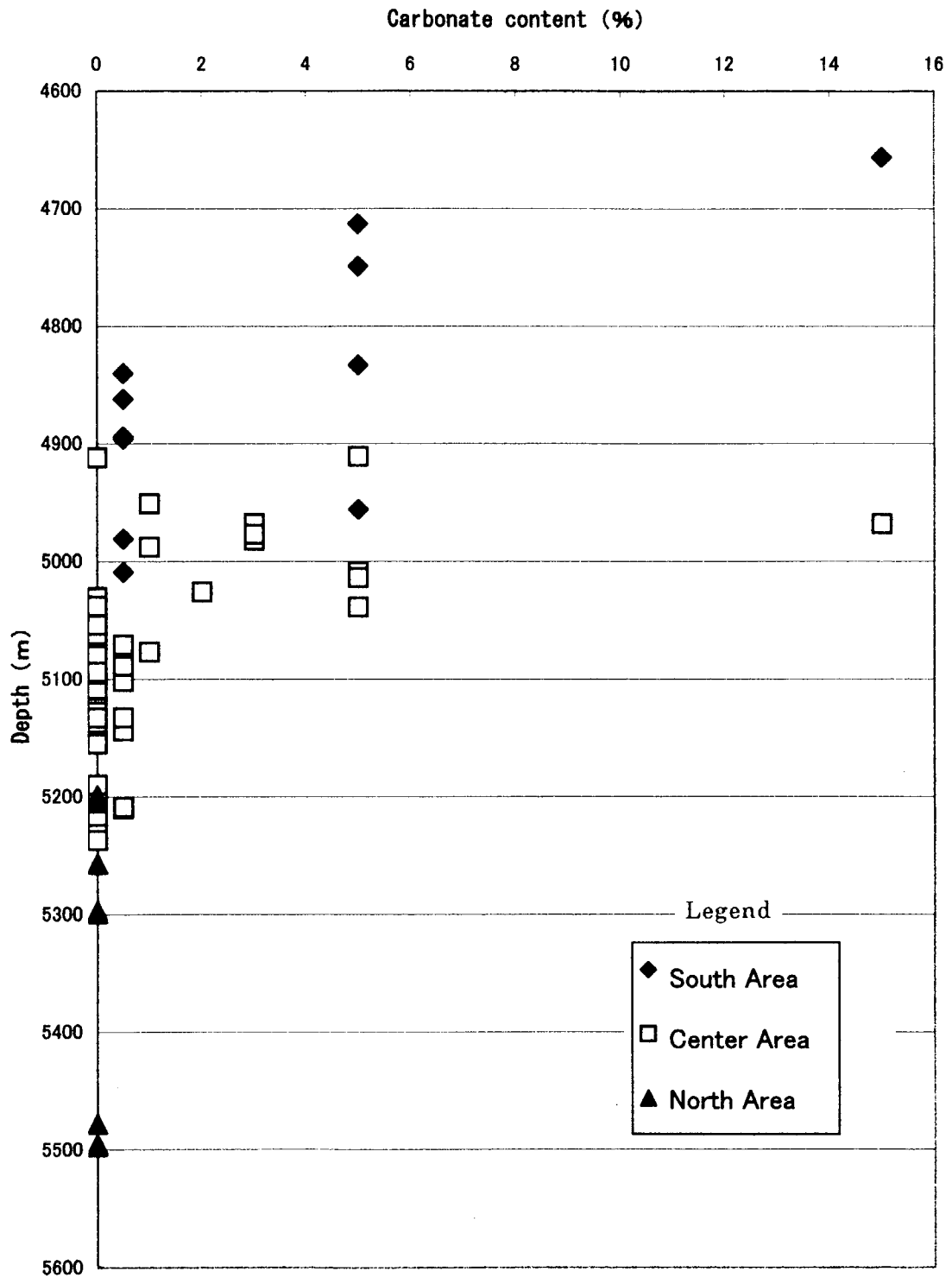


Figure 3-3-2 Relations between Water Depth and Carbonate Content

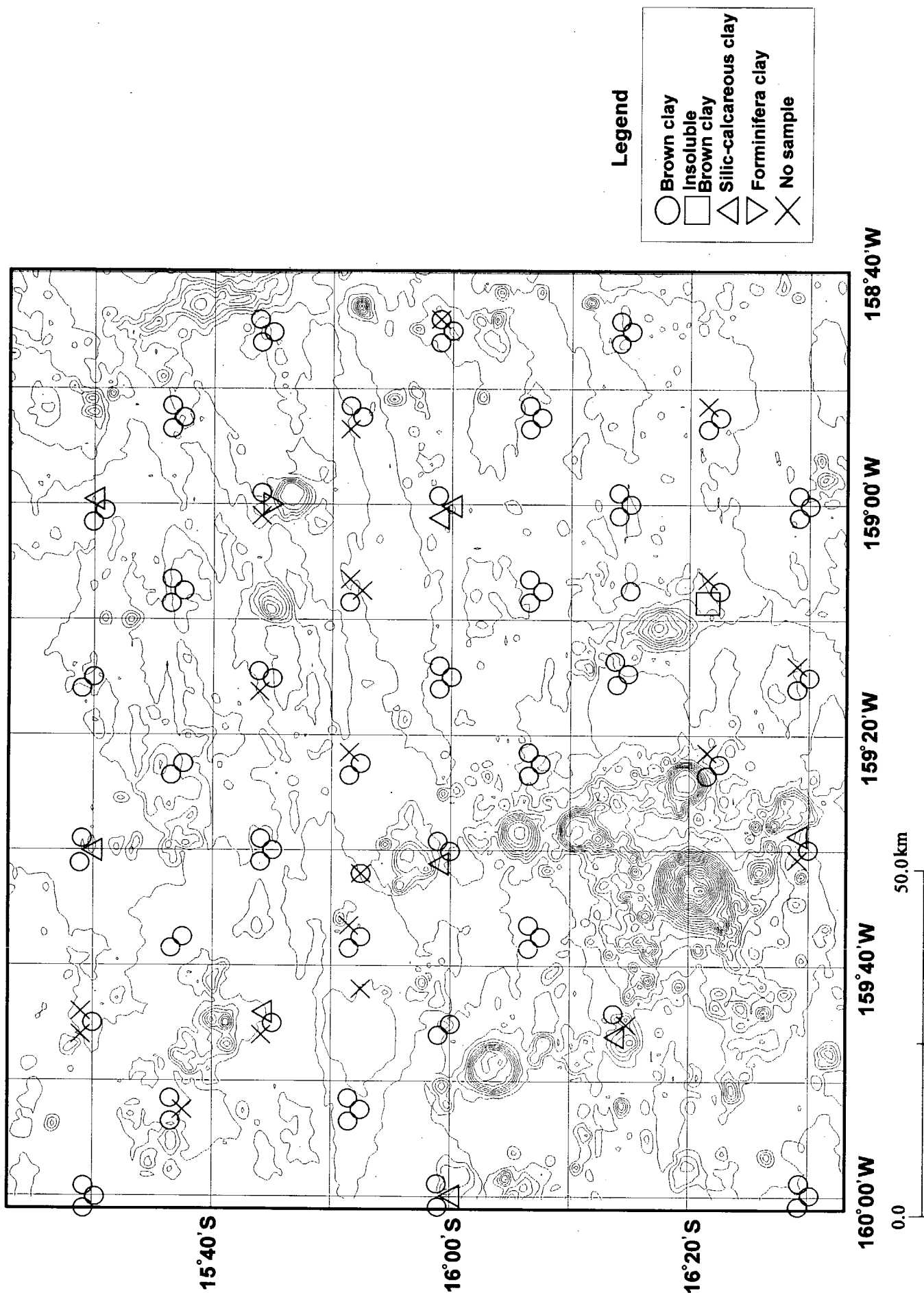


Figure 3-3-3 Distribution of Bottom Sediments (Center Area)

Table 3-3-3 Results of Deep-sea Sediments Sampling (Center Area)

Classification		Nmber of Sampling Site	Ratio(%)	
Brown clay (BC)		96	89	98
Calcareous sediments	Calc-siliceous clay (CSC)	9	8	
	Calcareous clay (CC)	1	1	
Insoluble brown clay (IBC)		2	2	2

<South Area>

In the South Area, FG, SC, and LC sampling were carried out at a total of 72 points during the past and present survey, and deep-sea sediments were collected at 51 points. The ratio of sediments collected is shown in Table 3-3-4 and the distribution of the deep-sea sediments in Figure 3-3-4.

The deep-sea sediments of this area are mostly brown clay and these are distributed in most of the area. Calcareous sediments, similar to the Center Area, occur sporadically in relatively shallow zones constituting plateau. Insoluble brown clay is distributed in relatively deep zones in the central part of the area.

Table 3-3-4 Results of Deep-sea Sediments Sampling (South Area)

Classification		Number of Sampling site	Ratio(%)	
Brown clay (BC)		39	76	88
Calcareous sediments	Calc-siliceous clay (CSC)	5	10	
	Calcareous clay (CC)	1	2	
Insoluble brown clay (IBC)		6	12	12

<North Area>

In the North Area, FG, SC, and LC sampling were carried out at a total of 18 points during the past and present survey, and deep-sea sediments were collected at 17 points. The ratio of sediments collected is shown in Table 3-3-5 and the distribution of the deep-sea sediments in Figure 3-3-5.

A small number of sampling was carried out in this area because this was a primary reconnaissance survey. In addition to this the sampled sites were deeper than 5,100m and below CCD. Thus the samples contained only brown clay and insoluble clay, and calcareous sediments such as calc-siliceous clay (CSC) and calcareous clay (CC) were not found.

Table 3-3-5 Results of Deep-sea Sediments Sampling (North Area)

Classification	Number of Sampling Site	Ratio (%)
Brown clay (BC)	13	76
Insoluble brown clay (IBC)	4	24

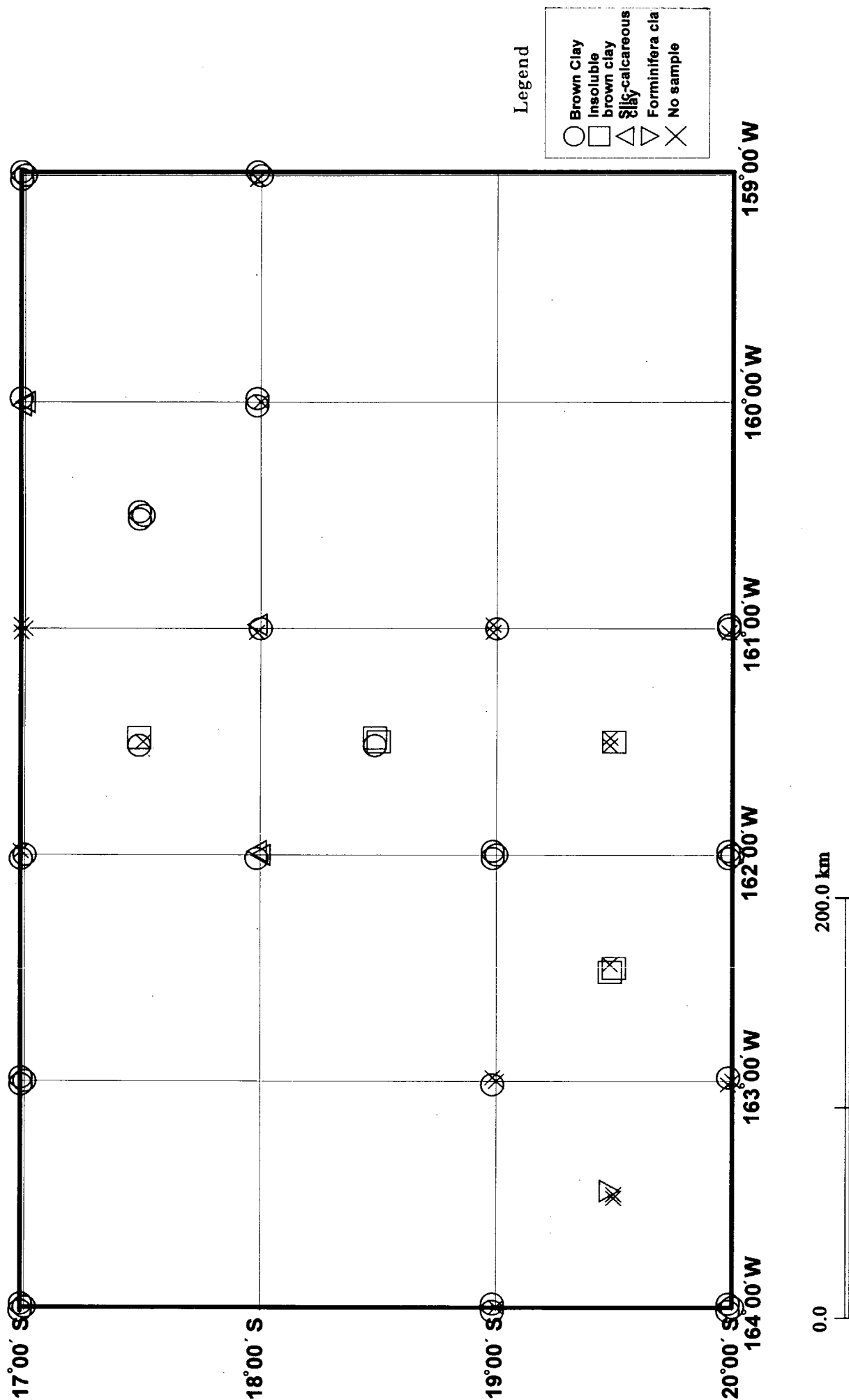
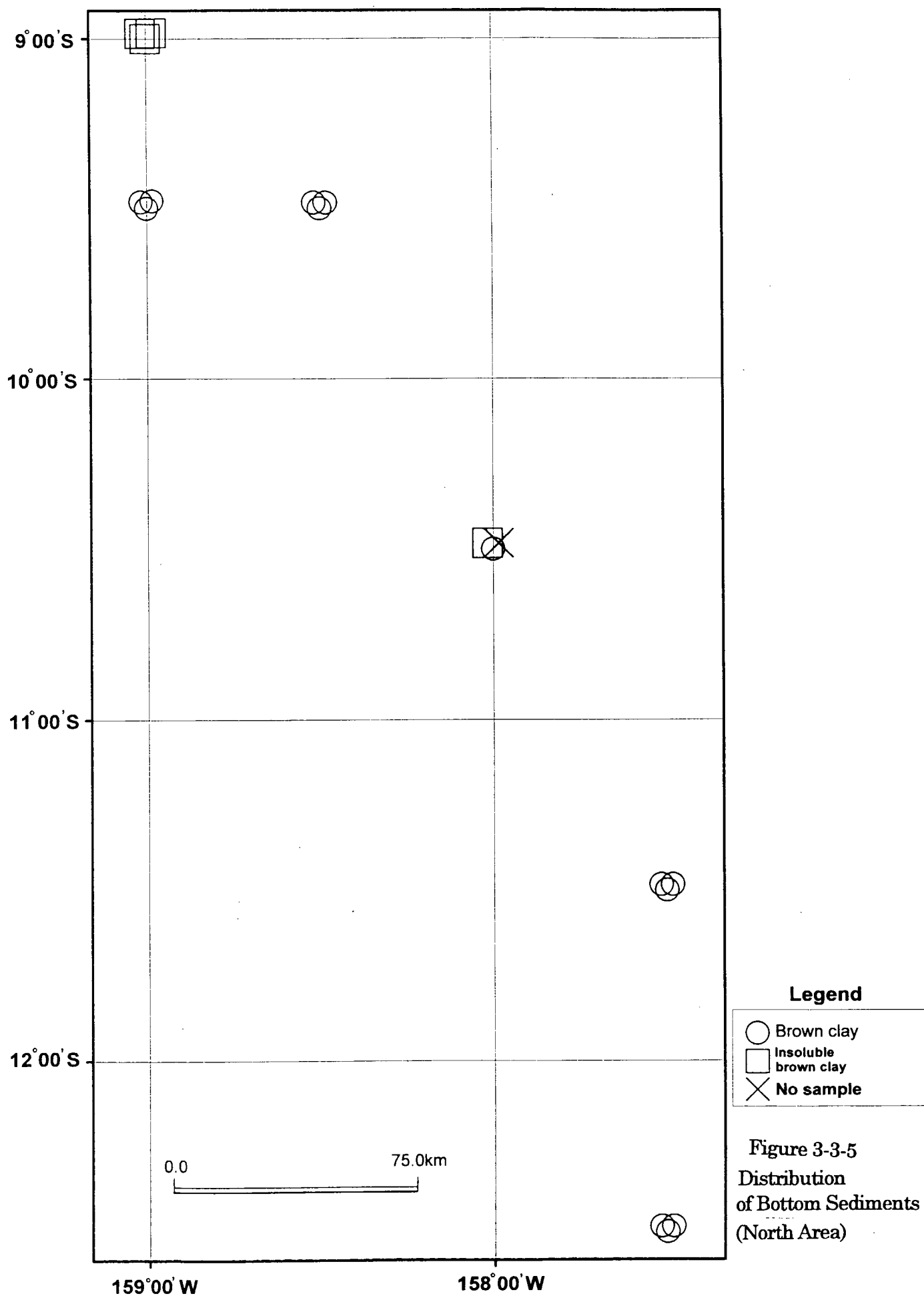


Figure 3-3-4 Distribution of Bottom Sediments (South Area)



(6) Chemical Composition of Deep-sea Sediments

Nineteen SC and LC sediments samples collected from nine points were chemically analyzed. Analytical method and detection limits of each element are shown in Table 3-3-6 and the results of unaided-eye observation of these samples are laid out in Table 3-3-7.

Water content of the analyzed samples from the deep seafloor was high and it varied considerably. Therefore the H_2O values were subtracted from the results and the remainder was recalculated to a total of 100%. The results are shown in Table 3-3-8 and the vertical variation of the chemical composition in Figure 3-3-6.

Table 3-3-6 Analytical Methods

Components	Method	Detection limit
SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3 , MnO , MgO , CaO , BaO , Na_2O , K_2O , P_2O_5 , FeO	ICP emission spectrometry	0.01%
LOI	Neutralization titration	0.01%
CO_2 , H_2O^+ , H_2O^-	Gravimetry	0.01%
	High frequency induced infrared absorption spectroscopy (LECO)	0.01%
Pb, Zn, Ni, Cu, Co, Sr, V, Mo, Y	ICP mass spectrometry	1ppm
B	Neutron activation analysis	1ppm
As	Atomic absorption analysis	1ppm

According to the results of X-ray analyses of the past surveys (JICA · MMAJ, 1986, 1987, 1991), the deep-sea sediments of the survey area contain, as main constituents, clay minerals such as illite, montmorillonite, and chlorite as well as quartz and plagioclase.

The chemical nature of the sediments of each area is reported below. The chemical composition of deep-sea red clay is shown in Table 3-3-9 for reference.

<Center Area>

Regarding the surface sediments within 15cm from the seafloor, the SiO_2 ranges from 40.87 to 45.58% and the Al_2O_3 content from 10.36% to 14.52% and these values are lower than the contents of the typical deep-sea sediments, the deep-sea red clay. TiO_2 content of one sample is somewhat low at 0.78%, but other samples contain 1.74~2.00% which is higher than that of the red clay. Fe_2O_3 , CaO , and MnO contents are also somewhat higher than those of red clay at 11.94 to 14.50%, 2.99 to 9.15%, and 2.21 to 5.70%, respectively. It is inferred, from the low SiO_2 and Al_2O_3 contents and high Fe_2O_3 and MnO contents, that supply of terrigenous clay was small or deposition was difficult at the time of sedimentation and the conditions were favorable for the deposition of iron and manganese hydroxides. The average values of Al/Ti of oceanic basalt, andesite, and granite are 11, 22, and 32 respectively (Lisitzin, 1984). The average Al/Ti values of surface unconsolidated sediments of the Center Area are 5.72~11.73. This indicated that these are weathered products of oceanic

Table 3-3-7 Description of Deep-sea Sediments Samples for Chemical Analysis

Area	Sample No.	Depth	Sample Code	Sampling Point	Description	HCl	H ₂ O ₂
South Center	00S1934SC04	4862m	FS01	0-5 cm	Brown clay. Containing a few fine sand.	±	+
	00S1736SC31	5071m	FS01	5-10 cm	Brown clay, uniform, no sand grain contained.	-	+
	00S1736LC46	5133m	FS01	5-10 cm	Brown clay, uniform, no sand grain contained.	-	+
			FS03	100-105 cm	Brown clay, uniform, no sand grain contained.	-	+
			FS05	200-205 cm	Brown clay, uniform, no sand grain contained.	-	+
			FS08	325-330 cm	Brown clay, uniform, no sand grain contained.	-	+
	00S1636SC19	4982m	FS01	0-10 cm	Brown clay, uniform, no sand grain contained.	-	+
	00S1636LC34	5062m	FS01	5-10 cm	Brown clay, uniform, no sand grain contained.	-	+
			FS03	100-105 cm	Brown clay with a few fine to medium sand grains.	-	++
					Brown clay covering crust, with dark color and low water content.	-	++
			FS05	172-177 cm	Hard brown clay with dark color and low water content. Substrate of crust.	-	++
	00S1636SC37	5233m	FS06	181-186 cm	Core bottom. Hard and uniform clay with dark color and low water content.	-	++
			FS10	320-325 cm	Core bottom. Hard and uniform clay with dark color and low water content.	-	++
			FS01	0-10 cm	Brown clay, uniform, no sand grain contained.	-	+
			FS01	10-15 cm	Containing nodules and crust fragments. Dark brown color and uniform texture.	-	+
North	00S1636LC50	4912m	FS03	115-120 cm	Containing nodules and crust fragments. Dark brown color and uniform texture.	-	+
					Brown clay with a few fine to medium sand grains.	-	+
			FS01	0-5 cm	Brown clay with a few fine to medium sand grains.	-	+
			FS03	10-15 cm	Brown clay with a few fine to medium sand grains.	-	++
	00S1338SC01	5199m	FS05	100-105 cm	Core bottom. Hard brown clay with a few very fine sand to silt grains.	-	++

Table 3-3-8 Chemical Composition of Deep-sea Sediments

No.	Sample No.	point	Components and Values(%)																
			SiO2	TiO2	Al2O3	Fe2O3	FeO	MnO	MgO	CaO	BaO	Na2O	K2O	P2O5	CO2	H2O+	H2O-	LOI	TOTAL
1	00S1934SC04	0-5 cm	38.69	1.03	11.60	8.94	0.25	1.69	3.09	4.88	0.112	4.91	1.92	0.57	3.19	1.16	2.20	22.59	100.16
2	00S1736SC31	5-10 cm	37.65	1.59	12.05	10.87	0.17	2.08	3.33	2.95	0.186	5.45	1.87	0.63	1.14	2.63	6.10	21.83	100.47
3	00S1736LC46	5-10 cm	38.26	1.61	12.33	10.83	0.15	2.02	3.28	3.02	0.178	5.02	1.89	0.60	1.50	4.21	9.24	21.47	100.48
4		100-105cm	38.60	1.91	11.45	10.69	0.18	1.64	3.15	3.20	0.145	4.83	1.96	0.60	0.62	1.72	4.11	19.84	98.05
5		200-205cm	39.91	1.45	12.12	9.43	0.38	1.99	3.02	2.66	0.088	4.61	2.25	0.74	0.95	4.67	10.70	19.81	98.37
6		325-330cm	39.35	1.54	10.92	9.70	0.40	1.60	2.41	2.15	0.041	6.02	2.86	0.67	0.22	2.37	4.98	21.78	99.40
7	00S1636SC19	0-10cm	34.20	1.46	10.89	9.99	0.15	1.85	2.97	7.66	0.153	4.78	1.72	0.59	5.02	2.24	4.28	24.56	100.82
8	00S1636LC34	5-10cm	38.15	1.73	11.19	11.15	0.21	2.07	3.30	3.12	0.121	4.56	2.00	0.79	1.80	6.12	11.30	21.62	99.89
9		100-105cm	39.59	1.34	11.98	9.95	0.32	2.11	2.83	3.08	0.064	4.72	2.34	1.10	0.59	4.64	8.75	20.42	99.78
10		172-177cm	22.58	0.59	5.50	22.28	0.20	5.91	2.40	1.81	0.117	3.44	1.82	1.13	0.48	5.99	14.00	32.42	100.08
11		181-186 cm	16.76	0.38	4.48	25.36	0.22	7.65	2.12	1.48	0.131	3.08	1.38	0.95	0.11	5.56	11.00	35.07	98.93
12	00S1636SC37	325-330cm	39.33	0.80	11.74	9.28	0.25	2.72	2.14	3.30	0.036	5.08	3.07	1.67	0.66	5.74	9.59	21.06	100.44
13		0-10cm	35.81	1.58	11.55	11.95	0.15	2.38	3.24	2.75	0.142	5.34	1.82	0.61	1.25	3.85	7.63	23.38	100.56
14		10-15cm	33.45	0.61	8.13	10.28	0.51	4.47	2.82	2.35	0.035	5.97	2.16	1.08	0.33	6.27	13.30	27.97	99.80
15		115-120 cm	33.84	0.54	7.24	10.77	0.37	4.88	3.09	2.43	0.041	5.90	1.95	1.17	0.44	5.32	12.60	27.76	99.94
16	00S1338SC01	0-5cm	41.32	0.98	12.39	8.14	0.18	1.84	2.26	2.75	0.041	5.30	3.16	1.18	0.92	4.46	12.80	20.49	99.99
17	00S1138LC01	10-15cm	40.65	0.92	11.85	9.03	0.17	2.14	2.67	2.80	0.040	4.99	2.68	1.12	1.47	4.48	10.50	20.96	99.98
18		100-105cm	45.00	0.55	13.36	5.26	0.30	1.80	1.59	2.81	0.023	5.32	4.28	1.54	0.77	4.65	10.60	19.17	100.98
19		215-220 cm	42.50	0.82	12.51	6.88	0.27	1.97	2.22	3.58	0.032	4.99	3.58	1.83	0.59	4.30	9.08	19.50	100.65

No.	Sample No.	point	Components and Values(%)												
			As	Co	Cu	Pb	Mo	Ni	Sr	V	Y	Zn	B		
1	00S1934SC04	0-5 cm	33	196	224	66	6	256	320	170	-	120	-		
2	00S1736SC31	5-10 cm	11	192	288	58	9	240	328	185	-	120	115		
3	00S1736LC46	5-10 cm	18	203	278	68	13	252	306	175	-	112	115		
4		100-105cm	20	167	299	56	10	182	344	194	-	122	110		
5		200-205cm	19	235	314	64	21	281	299	170	-	118	120		
6		325-330cm	1	145	290	44	17	188	293	165	-	158	130		
7	00S1636SC19	0-10cm	16	177	342	58	10	223	501	191	-	128	110		
8	00S1636LC34	5-10cm	29	193	325	62	13	243	339	195	-	130	-		
9		100-105cm	28	241	387	72	20	309	307	177	-	124	110		
10		172-177cm	266	119	788	110	172	680	455	695	-	302	140		
11		181-186 cm	279	99	643	130	229	391	551	774	-	346	150		
12	00S1636SC37	325-330cm	34	282	245	60	54	284	258	167	-	108	105		
13		0-10cm	25	199	365	64	19	263	365	238	-	146	120		
14		10-15cm	35	253	279	66	100	409	259	185	-	130	96		
15		115-120 cm	36	255	271	62	98	437	239	178	-	134	97		
16	00S1338SC01	0-5cm	12	162	271	48	12	270	238	128	-	86	86		
17	00S1138LC01	10-15cm	17	168	282	48	24	267	233	134	-	100	93		
18		100-105cm	9	172	141	40	28	196	174	83	-	62	58		
19		215-220 cm	9	237	230	46	36	326	260	128	-	110	85		

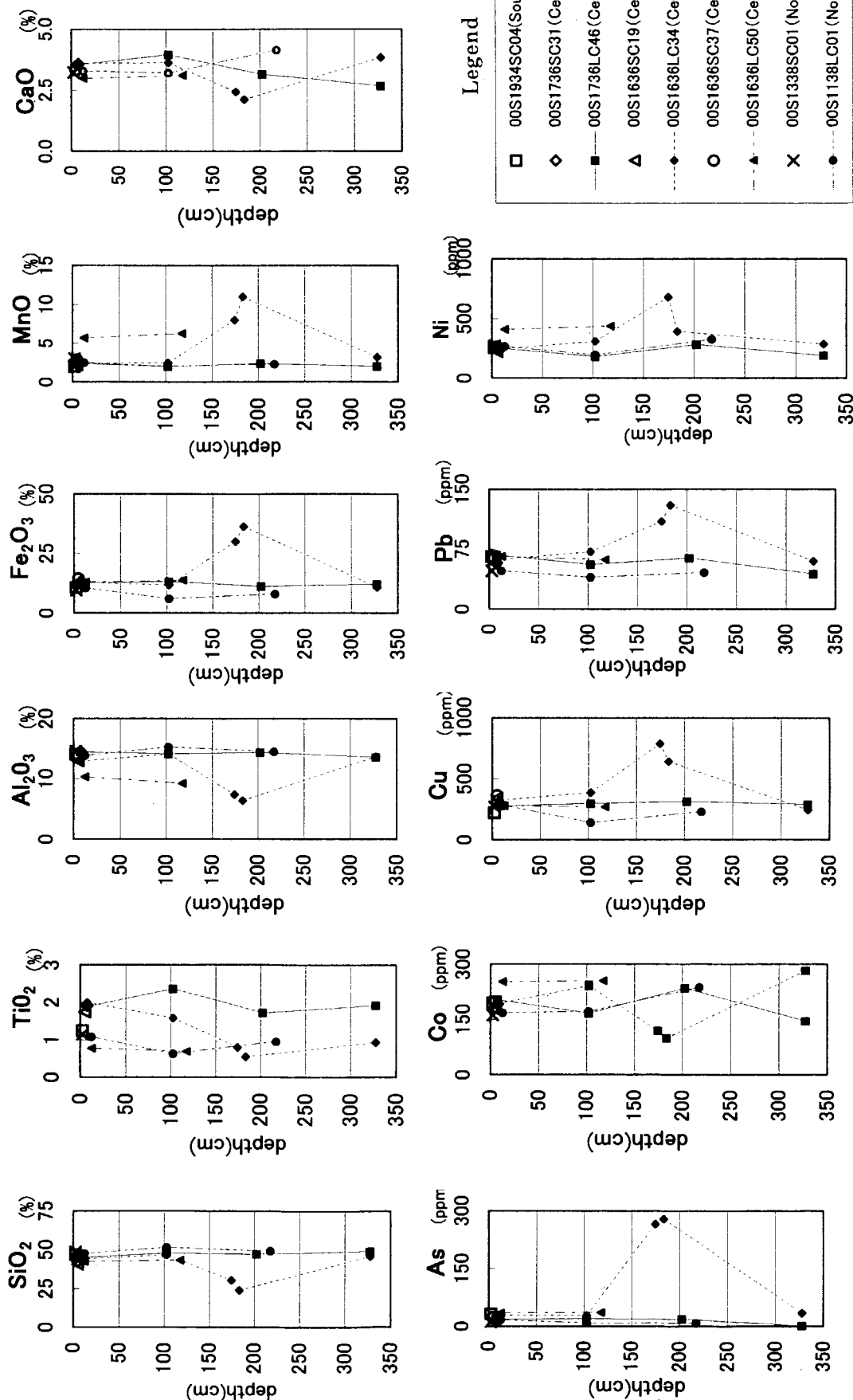


Figure 3-3-6 Results of Chemical Analysis of Bottom Sediments

basalt. This is harmonious with the inclusion of montmorillonite, which is believed to be the weathered product of basalt, in the above sediments. The somewhat high content of Ca is inferred to be due to the undissolved calcite remaining at sampling depth (4,912~5,233m) near CCD around 5,000m. The CaO content of the samples is highest at 9.15% in the sample from relatively shallow 4,982m depth.

Crusts with average thickness of 5mm occur near 177cm depth in 00S1636LC34. The vertical variation of the chemical composition indicate clearly lower SiO₂, TiO₂, Al₂O₃, CaO, and Co values and higher Fe₂O₃, MnO, As, Cu, Pb, and Ni contents immediately above and below the crusts. This fact shows that a period of concentration of Fe, Mn, As, Cu, Pb, Ni and other metals occurred around the time of crust formation. Otherwise significant vertical chemical variation is not observed.

<South Area>

The deep-sea sediments of this area contain smaller amounts of SiO₂ and Al₂O₃ than the deep-sea red clay at 47.18 and 14.14% respectively. However Fe₂O₃ and MnO contents are closer to that of the deep-sea red clay and somewhat lower than the Center Area at 10.90% and 2.06%. The sampling point is believed to be shallower than CCD at 4,862m, and the CaO content is 5.95% and is high.

<Northern Sea Area>

The deep-sea sediments of this area contain smaller amounts of SiO₂ and Al₂O₃ than the deep-sea red clay at 48.66, 47.82% and 14.59, 13.94% respectively. However Fe₂O₃ and MnO contents are closer to that of the deep-sea red clay at 9.59, 10.62 and 2.17, 2.52%. Compared with the values of the Center Area SiO₂ content is higher and Fe₂O₃, MnO contents are lower. The sampling points are deep at 5,199m and 5,478m and the CaO content is somewhat low at 3.24 and 3.29%. Prominent vertical chemical variation is not observed and the tendency of slight increase of Co and decrease of TiO₂, Fe₂O₃, and Cu contents are seen.

Table 3-3-9 Chemical Composition of Deep-sea Red Clay

(%)

	Mixed sample of Pacific, Atlantic and Indian Ocean by Clarke and Steiger	Samples of the Challenger expedition	Samples by the Meteor	Red clay sampled at South-West area of North Pacific Ocean by Ishibashi and Harada	Red clay sampled at North Pacific Ocean by Hamaguchi
Number of samples	P51, A8, I 2			6	16
SiO ₂	54.48	54.28	55.16	50.77	52.45
TiO ₂	0.98	—	0.96	—	0.84
Al ₂ O ₃	15.94	16.41	16.79	20.75	16.05
Fe ₂ O ₃	8.66	13.58	5.65	10.94	8.26
FeO	0.84	1.26	1.38	—	—
MnO ₂	1.21	1.62	4.13	2.01	1.12
MgO	3.31	1.76	2.76	3.08	3.35
CaO	1.96	0.74	0.27	1.72	2.44
Na ₂ O	2.05	1.37	2.41	1.39	4.98
K ₂ O	2.85	1.61	1.09	2.78	2.57
H ₂ O	7.04	7.02	9.08	9.75	7.34
P ₂ O ₃	0.3	0.35	0.32	0.28	0.34
	99.62	100	100	103.49	99.84

From Chemistry of Sediments (Toukai University Public)

(7) Identification of Fossils in Deep-sea Sediments

Fossils in the deep-sea sediments collected by SC and LC were identified in order to determine the age of deposition and sedimentary environment. The samples for fossil identification are listed in Table 3-3-10. They are; 2 samples from 1 locality in the South Area, 15 samples from 4 localities in the Center Area, and 3 samples from 1 locality in the North Area. During the past survey, fossils have been identified from 12 samples from 3 localities in the South Area and 6 samples from 2 localities in the North Area (JICA·MMAJ, 1986, 1991). The results of the present survey are laid out in Tables 3-3-11 and 3-3-12. Foraminifera and calcareous nannofossils were not available in quantities sufficient for analysis in all samples and identification of only radiolaria fossils and ichthyolith were carried out. Identification of ichthyolith was based on Doyle and Riedel (1979). Photographs of representative radiolaria fossils and ichthyolith observed are shown in Figures 3-3-7 and 3-3-8. The geologic age of the fossils is shown together with geologic columns in Figure 3-3-1.

The results of fossil identification are as follows.

Table 3-3-10 Description of Deep-sea Sediments samples for Micro-fossil Identification

Area	Sampling No.	Depth	Sample code	Sampling point	Description
South Area	00S1934SC04	4,862m	FS01	0-5 cm	Brown clay with a few fine sand grains.
			FS03	16-20 cm	Brown clay with a few fine sand grains.
Center Area	00S1736LC46	5,133m	FS01	5-10 cm	Brown clay, uniform, no sand grain contained.
			FS03	100-105 cm	Brown clay, uniform, no sand grain contained.
			FS05	200-205 cm	Brown clay, uniform, no sand grain contained.
			FS08	325-330 cm	Core bottom. Brown clay, uniform, no sand grain contained.
	00S1636LC34	5,062m	FS01	5-10 cm	Brown clay, uniform, no sand grain contained.
			FS03	100-105 cm	Brown clay, with a few fine to medium sand grains.
			FS05	172-177 cm	Brown clay with dark color and low water content, covering crust.
			FS06	181-186 cm	Hard brown clay with dark color and low water content, substrate of crust.
			FS10	320-325 cm	Core bottom. Hard and uniform clay with dark color and low water content.
	00S1636LC43	5,129m	FS01	0-5 cm	Brown clay, uniform, no sand grain contained.
			FS04	80-85 cm	Brown clay covering crust with a few fine to medium sand grains, maximum size of grain 2mm across..
			FR01	85-90 cm	Thin silt rock layer between crust, showing a pale brown color, includes small black grain (micro-nodules?)
			FR02	90-95 cm	Silt stone constituting substrate of crust. Shows pale brown color and has coating of Mn-oxide.
North Area	00S1636LC50	4,912m	FS01	10-15 cm	Fragments of nodules and crust contained, shows dark brown color and uniform texture.
			FS03	115-120 cm	Core bottom. Hard brown clay with a few very fine sand to silt grains..
			FS01	10-15 cm	Brown clay with a few fine to medium size sand grain.
	00S1138LC01	5,478m	FS03	100-105 cm	Brown clay with a few fine sand.
			FS05	215-220 cm	Core bottom. Brown clay with a few fine sand.

Table 3-3-11 List of Identified Radiolarias

Abundance	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	00S1934		00S1736			00S1636			00S1636			00S1636			00S1636			00S1138		
	FS01	FS03	FS01	FS03	FS05	FS08	FS01	FS03	FS05	FS06	FS10	FS01	FS04	FS01	FS02	FS01	FS03	FS01	FS03	FS05
	C	B	R	B	VR	B	R	B	VR	B	B	C	B	B	B	VR	B	C	VR	B
<i>Acrosphaera lappacea</i> (Haeckel)	x											x								
<i>Acrosphaera spinosa</i> (Haeckel)	x		x				x					x				x		x		
<i>Collosphaera tuberosa</i> Haeckel	x						x					x						x		
<i>Disolenia zanguebarica</i> (Ehrenberg)	x											x						x		
<i>Siphonospaera</i> spp.	x		x				x					x				x		x		
<i>Acoprurum sauraxonium</i> Haeckel	x		x				x					x						x		
<i>Cenospaera</i> ? sp.	x		x		x		x					x						x		
<i>Elipsoxiphus atracrus</i> Haeckel	x		x				x					x						x		
<i>Hexaconium anaximandri</i> (Haeckel)	x																	x		
<i>Heliodiscus asteriscus</i> Haeckel	x																	x		
<i>Didymocyrtis tetrathalamus</i> (Haeckel)	x		x				x					x						x		
<i>Syloclamydium asteriscus</i> Haeckel	x						x					x						x		
<i>Sylodictya multispina</i> Haeckel	x		x									x						x		
<i>Sylodictya camerina</i> Campbell and Clark	x						x					x								
<i>Dictyocoryne profunda</i> Ehrenberg			x									x						x		
<i>Dictyocoryne truncatum</i> (Ehrenberg)	x											x						x		
<i>Euchlontia furcata</i> Ehrenberg	x						x					x						x		
<i>Spongaster tetras tetras</i> Ehrenberg							x					x						x		
<i>Spongocore cylindrica</i> (Haeckel)	x																			
<i>Octopyle stenozona</i> Haeckel												x								
<i>Tetrapyle octacantha</i> Muller	x						x					x						x		
<i>Larocospira quadrangula</i> Haeckel	x											x						x		
<i>Lithelium minor</i> Jorgensen	x											x								
<i>Spongurus</i> ? elliptica (Ehrenberg)	x		x									x								
<i>Giraffospyris angulata</i> (Haeckel)	x											x						x		
<i>Liriospyris reticulata</i> (Ehrenberg)	x																			
<i>Liriospyris</i> sp. (juvenile)	x		x				x					x						x		
<i>Cycladophora bicornis</i> Popofsky group	x																			
<i>Eucyrtidium acuminatum</i> (Ehrenberg)	x											x								
<i>Eucyrtidium anomalum</i> (Haeckel)	x						x					x								
<i>Eucyrtidium calvertense</i> Martin	x											x								
<i>Eucyrtidium hexastichum</i> (Haeckel)	x																			
<i>Eucyrtidium punctatum</i> (Ehrenberg)	x																			
<i>Lithopera bacca</i> Ehrenberg									x											
<i>Pterocanium praetextum</i> (Ehrenberg)												x						x		
<i>Pterocanium trilobum</i> (Haeckel)	x											x								
<i>Carpocanistrum</i> spp.	x						x					x								
<i>Anthocyrtidium zanguebaricum</i> (Ehrenberg)												x								
<i>Lamprocyrtes nigriniae</i> (Cauket)	x											x								
<i>Theocorythium trachelium</i> (Ehrenberg)	x											x						x		

C = common, R = rare, VR = very rare, B = barren

Table 3-3-12 List of Identified Ichthyolith

Sampling No.	00S1934 SC04		00S1736 LC46				00S1636 LC34					00S1636 LC43				00S1636 LC50		00S1138 LC01		
Sample Code	FS01	FS03	FS01	FS03	FS05	FS08	FS01	FS03	FS05	FS06	FS10	FS01	FS04	FR01	FR02	FS01	FS03	FS01	FS03	FS05
Species Name/ Abundance	R	R	R	R	R	R	R	C	C	R	VR	R	C	VR	R	C	C	C	C	A
Assymmetrical peaks narrow depression	x																			
Curved triangle pointed margin	x	x	x	x		x		x	x			x	x	x		x		x	x	x
Flexed narrow triangle 120-128		x														x				
Five peaks flared base	x								x							x	x			
Flexed triangle 102-112	x	x	x	x	x	x	x	x	x		x	x	x			x	x	x	x	x
Flexed triangle 115-118	x	x		x				x		x			x					x		x
Flexed triangle shallow inbase		x		x								x								
Flexed triangle shallow inbase >120		x		x		x			x	x		x	x					x		x
Kite-shaped elongate prominence										x										
Kite-shaped longitudinal line															x	x	x			
Large with numerouse lines		x		x								x						x		x
Long triangle stepped margin			x														x			
Long triangle thin wall													x			x				x
Narrow curved triangle																				x
Narrow curved triangle small top						x							x							
Narrow triangle cross-hachured					x			x	x						x	x	x	x	x	x
Narrow triangle ragged base		x				x	x	x	x											
Narrow triangle sharply pointed															x					
Narrow triangle straight inbase	x	x		x	x	x	x	x	x		x	x	x		x	x	x	x	x	x
Plain and lined lanceolate																	x			
Pointed and skirted								x		x			x		x					
Prominent polygon									x				x				x			
Rectangular irregularly saw-toothed					x			x										x	x	
Rectangular saw-toothed									x				x			x		x	x	x
Rounded apex triangle			x	x			x	x				x	x					x	x	
Short kite-shaped																				x
Short side peaks differentiated margin									x				x			x				
Short triangle stepped margin				x		x			x				x						x	
Skewed four or five peaks						x	x	x	x		x		x		x			x	x	x
Small dendritic few radiating lines	x								x											
Small dendritic many radiating lines				x				x	x											
Small triangle long striation								x								x			x	
Straight flared triangle																				x
Striated blunt triangle																		x		
Three equaled peaks flared base						x							x			x	x			
Three similar peaks					x													x	x	
Triangle bowed inline	x																			
Triangle concave base	x	x	x	x									x							
Triangle curved base						x			x			x								
Triangle double flex														x		x	x			x
Triangle hooked margin	x		x	x				x												
Triangle inline halfway		x											x			x	x			x
Triangle long inline	x		x	x							x									
Triangle medium wing								x					x			x	x		x	
Triangle one canal above				x						x			x		x	x	x			x
Triangle pointed margin ends									x							x	x			
Triangle sigmoid	x																			
Triangle small top	x	x	x			x	x	x	x	x			x		x	x	x	x	x	x
Triangle with base angle										x						x	x			
Triangle with canals				x	x			x	x				x			x	x	x	x	x
Triangle with high inline apex			x		x		x	x					x			x		x		x
Triangle with parallel inline	x		x			x			x	x		x	x	x		x			x	x
Triangle with triangular projection	x				x	x		x	x					x	x	x	x		x	x
Two triangles																		x		
Wide crescent		x		x								x						x		
Wide triangle						x		x	x				x						x	x
Wide triangle keeled edges										x										
Wide triangle straight inbase					x			x	x	x		x	x					x	x	x

A: abundant, C: common, R: rare, VR: very rare

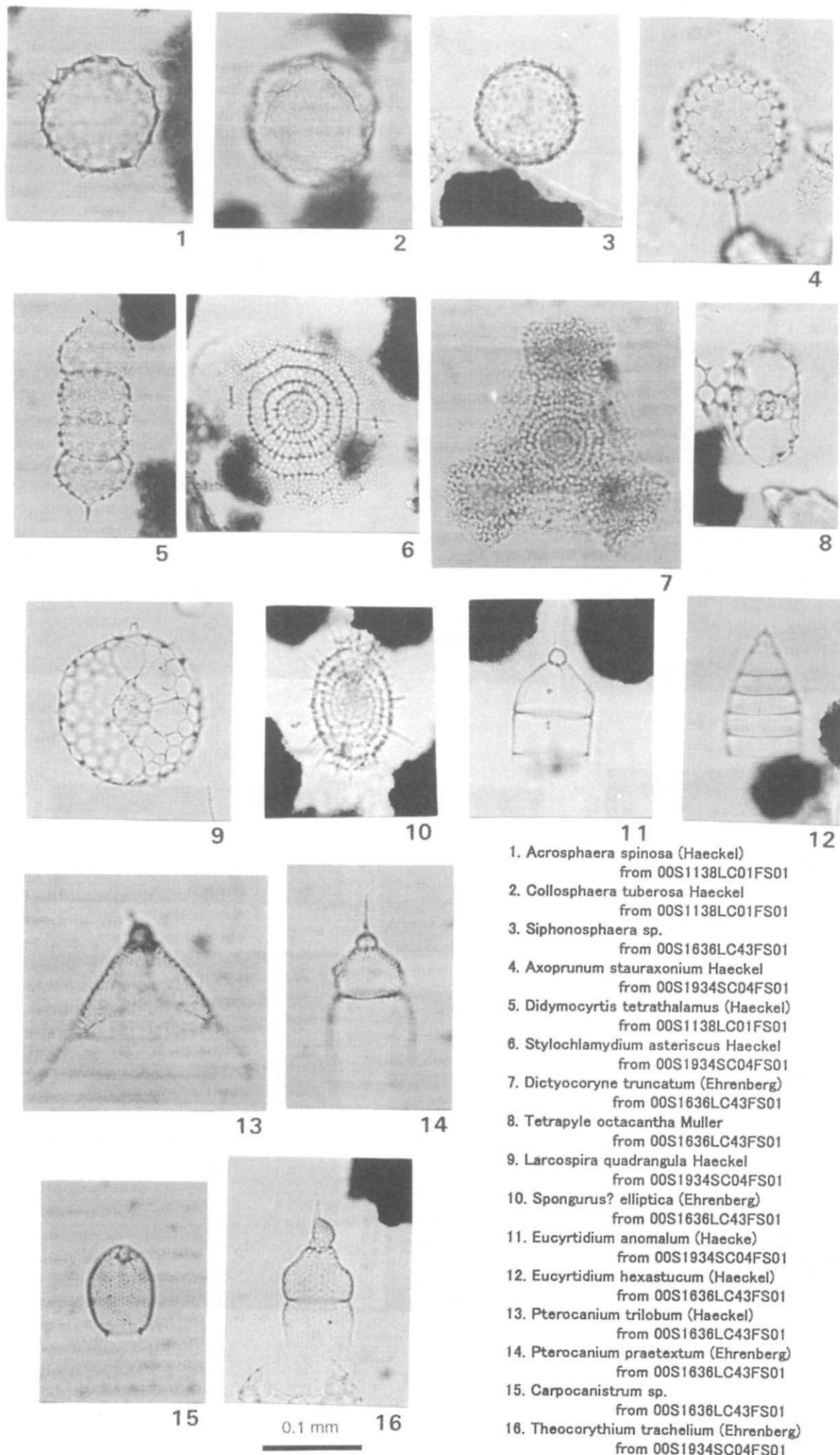
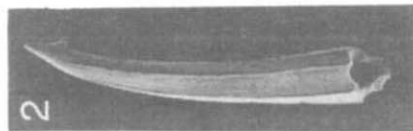


Figure 3-3-7 Species of Typical Radiolarian Fossil



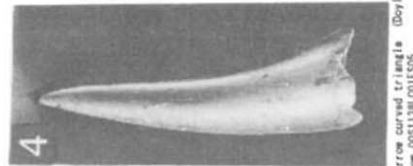
Triangle double flax
Dunsmuir et al.
from 0051138L.C01F505



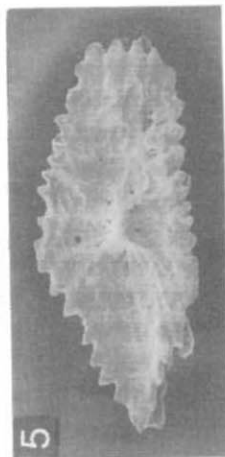
Triangle with triangular projection
Dunsmuir et al.
from 0051138L.C01F505



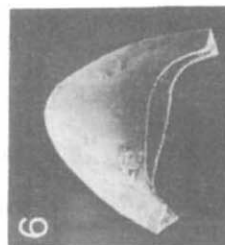
Curved triangle pointed margin
Dunsmuir et al.
from 0051138L.C01F505



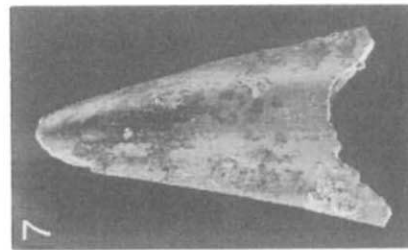
Narrow curved triangle
Dunsmuir et al.
from 0051138L.C01F505



Large with numerous lines
Dunsmuir et al.
from 0051138L.C01F505



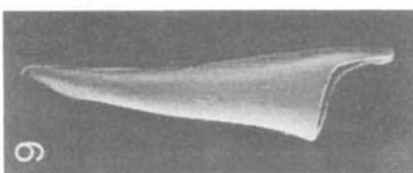
Wide triangle
Dunsmuir et al.
from 0051138L.C01F504



Triangle curved base
Dunsmuir et al.
from 0051138L.C01F501



Triangle concave base
Dunsmuir et al.
from 0051138L.C01F504

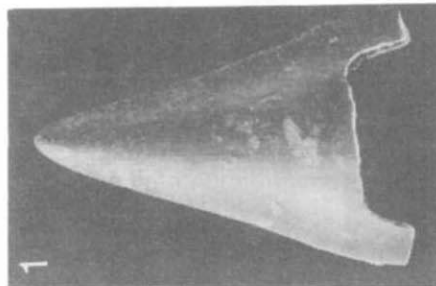


Triangle medium wing
Dunsmuir et al.
from 0051138L.C01F503

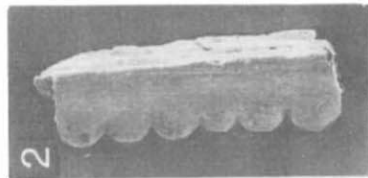


1-2
3-9
0.1mm

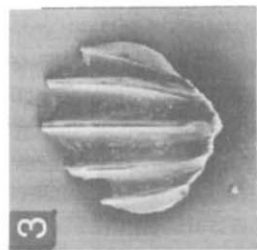
Figure 3-3-8 Microscopic Photographs
of Typical Ichtyolith



Wide triangle straight ribase
Dunsmuir et al.
from 0051138L.C01F504



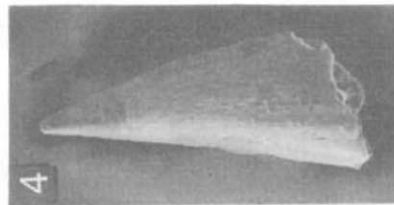
Rectangular ear-toothed
Dunsmuir et al.
from 0051138L.C01F505



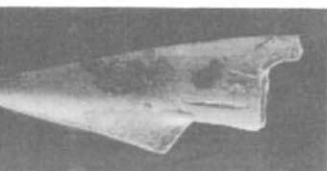
Sheen four or five peaks
Dunsmuir et al.
from 0051138L.C01F505



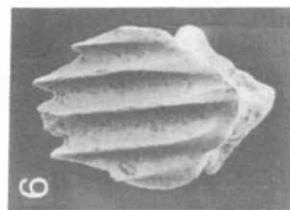
1
2-8
9
0.1mm



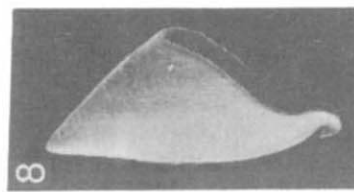
Triangle with conical base
Dunsmuir et al.
from 0051138L.C01F505



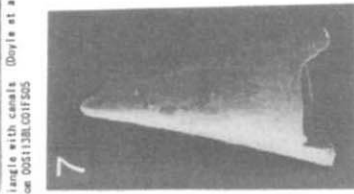
Fixed triangle 102-112
Dunsmuir et al.
from 0051138L.C01F503



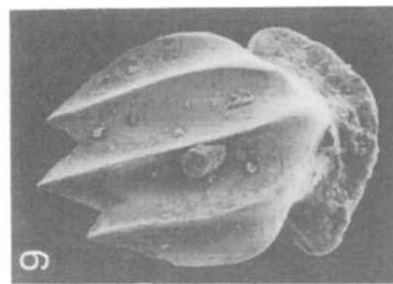
Five peaks flared base
Dunsmuir et al.
from 0051138L.C01F503



Triangle hooked margin
Dunsmuir et al.
from 0051138L.C01F501



Narrow triangle straight ribase
Dunsmuir et al.
from 0051138L.C01F504



Three equal peaks flared base
Dunsmuir et al.
from 0051138L.C01F503

<Center Area>

Radiolaria fossils, which can be identified, were obtained during the present and past surveys only from the seafloor surface and etched radiolaria microfossils were rarely observed in the lower layers and their species could not be identified.

All radiolaria fossils confirmed in the surface layers are of Quaternary age. *Collosphaeratulerosa* which first appeared in 500ka and other radiolaria which appeared later in the Pacific tropical to subtropical zones were confirmed.

Ichthyolith that could be used for age determination could not be obtained from samples in the surface layers. But ichthyolith indicating geologic age was confirmed from other samples. LC samples from four localities of the Center Area were divided into three geologic ages of post-Pliocene, pre-Pliocene, pre-late Miocene by ichthyolith specimens. "Two triangles" which appeared after Pliocene occurred in 00S1636LC50 only in layer at 115cm depth from the seafloor. "Pointed and skirted", "Flexed triangle shallow base" and other species which lived to Pliocene occur in the surface layers of samples 00S1636LC43, 00S1636LC34, and 00S1736LC46 from depths of 85cm, 100cm, and 100cm respectively. In 00S1636LC343, species which existed to late Miocene occur in mudstone within crusts and those which lived to Pliocene in mudstone substrata of crusts.

It is thus inferred that the deposition of the deep-sea sediments continued since pre-late Miocene and that the surface layers of the sediments of this area deposited under tropic to subtropical environment after 500ka. Since radiolaria hardly occur with the exception of the surface layers, the surface productivity of the ocean was low in the past and still is low at present. Ichthyolith was confirmed in all samples. General occurrence of ichthyolith in brown clay with very small content of terrigenous clastic material is a general characteristic of the oceanic sediments of low-productivity seas. This fact is not contradictory to the inference of low ocean productivity of this area. The deposition age of the sediments immediately above and below the crusts of 00S1636LC43 and 00S1636LC34 are considered to be pre-Pliocene and pre-late Miocene from ichthyolith respectively. Crust formation is believed to have been completed before Pliocene and the start of formation is not clear.

<South Area>

Identifiable radiolaria fossils were obtained only from the upper 10cm of the deep-sea sediments in this area as in the case of the Center Area. The confirmed radiolaria are of the same or similar species as those from the surface layer of the sediments from the Center Area.

Ichthyolith individuals which can be used for age determination do not occur in the surface layers of this area, and individuals which existed to Pliocene time were confirmed in samples collected from sediments 16~20cm below the surface.

From the above, it is believed that the deposition of the deep-sea sediments of this area has continued from pre-Pliocene time and that the surface layers are believed to have deposited under tropical to subtropical environment after 500ka, and the ocean productivity was and still is believed to be low.

<North Area>

Foraminifera fossils from 200ka to present were confirmed from the surface layers of this area during the past survey. Radiolaria fossils which appeared in 500ka were confirmed in the sediments of 10~15cm below from the surface during the present survey, and these sediments are thus inferred to have been deposited under tropical to subtropical environment after 500ka.

Ichthyolith individuals, which can be used for age determination, were confirmed only from the deepest part of the samples. These are species existed until late Miocene and thus it is inferred that the deposition of the deep-sea sediments continued from pre-Miocene time.

This area also is believed to have low oceanic surface productivity similar to the South and Center Areas.

(8) Thin Section Microscopy of Rocks

Rocks associated with crusts were collected from several FG and LC sampling localities in the Center and South Areas. Thin sections of these rocks were studied microscopically.

The results of microscopic observation are laid out in Table 3-3-13 and descriptions of each thin section are shown in Attached Table 1.

Table 3-3-13 Results of Microscopic Observation of Rock Thin Sections

Area	Sampling No.	Sample Code	Remarks
Center Area	00S1636LC43	T01	Mudstone under crust
South Area	00S2032FG06	T01	Substrate of crust

Sample Code	Rock	Description				
		Size	Figure	Rock	Texture	Alternation
00S1636LC43T01	Reddish brown clay					
00S2032FG06T01	Olivine basaltic brachia	10mm	brachia	Olivine asalt	porph, intg, sub-oph	Heavy

Sample Code	Description															Matrix description							
	Penocryst minerals					Matrix					Altered minerals												
	Q	Pl	Ol	Ho	Cpx	Pl	Ol	Ho	Cpx	G	Ch	Sm	Ze	Serp	Pal	Pl	Px	Ch	Op	Lim	Cal	Serp	Cly
00S1636LC43T01																.	.	⊙	△	.	○	.	⊙
00S2032FG06T01			○			⊙	△		○	○		⊙		○	⊙								⊙

Mineral

Texture

Quantity (%)

Q ; Quartz Pl ; Plagioclase Vc ; Vitro-clastic texture ⊙ ; Many >30%
Ol ; Olivine Ho ; Hornblende Isog ; Isogranular ○ ; Meddium 10~30%
Px ; Pyroxene Cpx ; Clinopyroxenes porph ; Porphyritic intg ; Intergranular △ ; Few 3~10%
O ; Opaque minerals Ch ; chlorite sub-oph ; Sub-ophitic . ; Very few <3%
Sm ; Smectite
Ze ; Zeolite Serp ; Serpentine
pal ; Palagonite Lim ; Limonite
G ; Volcanic glass Cal ; Calcareous mineral
Cly ; Clay mineral