Chapter 6 Discussions and Recommendations

6 - 1 Formation, Development of Seamounts and Occurrence of Cobalt-Rich Crusts

(1) Formation and development of seamounts

Occurrence of cobalt-rich crusts was confirmed in all MS10~MS13 areas. The collected crusts were thick with an average of 33.1~46.4mm, and the maximum exceeded 100mm in all areas.

The reason for the occurrence of thick crusts in this survey area is closely related to the process of formation of the seamounts of the area.

Basalt collected from the survey area was all clarified to belong to oceanic island basalt from the results of chemical analysis. The rocks were strongly altered and K-Ar age determination was not possible, but from identification of the fossils of MS10~MS12 areas, it was established that the seamounts of this survey area were formed before Paleogene, subsided and the summits were at deep seafloor by Eocene (38.5~45.5Ma). This result is harmonious with the results of rock age determination and fossil identification carried out on MS01~MS09 areas in 1997. It was shown that the seamount group near Anewetak Atoll, Ratak Chain, and Ralik Chain were formed at that time. The fact that these seamounts were submerged in old times is considered to be the prime reason for the growth of thick crusts.

Regarding the seamount in MS13 area, it was not possible to carry out rock age determination and fossil identification, and information on the formation process of the seamount could not be acquired. But many crusts and crust fragments over 100mm thick were collected, and it is highly possible that this seamount was submerged before Paleogene as in the cases of MS10~MS12 areas.

Generally thick crusts are developed on seamounts formed before Paleogene, and crusts and cobble crusts exceeding 50mm in thickness were collected from the seamounts in MS01~MS13 areas during the 1997 survey.

(2) Occurrence of cobalt-rich crusts

MS10~MS12 seamounts surveyed this year all have crusts and cobble crusts exceeding 100mm in thickness from the summit periphery to the upper slope. Particularly in MS12 area, it was confirmed that over 100mm crusts occur even on middle slope. In the waters of the Marshall Islands, thick crusts have been collected from the summit peripheries of other guyots.

In the four areas surveyed this year, rocks are exposed widely from the summit periphery to the upper slope with the exception of MS13 area, and the environment is favorable for crust growth. In parts of the summit periphery and the upper slope where unconsolidated sediments cover at present, the sediment cover is thin in many places, it is possible that the summit periphery was exposed for a long period of time.

Regarding the substrates of the crusts, basalt is strongly altered and limestone is phosphatized. The seamounts in three areas with the exception of MS13, the bathymetric contour are, although somewhat irregular, generally smooth and large scale collapse or caving have not taken place and the base has been stable. This again is a factor for the stable growth of the crusts. Also these three seamounts have not been affected by volcanism after middle Paleogene.

Regarding the seamount in MS13 area, the summit is covered by thin unconsolidated sediments, but it is also considered to have been submerged before Paleogene, and it is possible that thick crusts could occur under the unconsolidated sediments.

6 - 2 Future Work

The three seamounts in MS10~MS12 are dome-shaped guyots formed in Paleogene, and are similar to the seamounts of MS01~MS09 surveyed in 1996, in the trends regarding the occurrence and the metal grade of the cobalt-rich crusts On the other hand, the thickness of the crusts, average and the maximum, are higher in the seamounts surveyed this year, while the grade of the five major elements tend to be higher in the seamounts surveyed previously. However, the number of samples is insufficient for such comparisons, and thus it is deemed necessary to acquire further data in this marine area.

There are many unexplored seamounts which are considered to have been formed before Paleogene in the waters of the Republic of the Marshall Islands, and it will be necessary to survey the occurrence of cobalt-rich crusts in order to assess the general area and to determine the priority of detailed investigation.

Chapter 7 Summary

This is the fourth year of the third phase of the five-year SOPAC Program. This year, following the results of the survey in the exclusive economic zone of the Republic of the Marshall Islands in 1996, and that of the Federated States of Micronesia in 1997, topographic surveys and sampling for manganese crust deposits were carried out in the marine areas of both countries which were not studied in the previous surveys.

The duration of the survey cruise was 49 days, of which that in the waters of the Republic of the Marshall Islands was 27 days. This paper reports the results obtained in the EEZ of the Marshall Islands.

There are many oceanic islands, atolls and seamounts in the survey area. The survey was carried out in the western marine area of the Marshall Islands centered around the Anewetak Atoll and is located to the west of the 1996 survey area.

The survey was composed mainly of MBES topographic survey for preparing detailed topographic maps of the seamounts, and of sampling by chain bag dredge (CB), arm dredge (AD), and large corer (LC). Also seafloor observation by FDC, study of depositional conditions of unconsolidated sediments by SBP, and microtopography survey by SSS. Important samples were studied in laboratories on land by various methods including; ore assay and thin section microscopy. These together with the results of onboard analysis provided the basis for integrated analysis of the resource.

The combined summary of the survey results in 1996 and 1998 are in Table 7-1-1(1),(2).

(Topographic survey)

The survey area consisted of the exclusive economic zones of the Marshall Islands and of Micronesia. It was divided into the eastern sea area centered around the oceanic plateau with Anewetak Atoll, and the western sea area in the vicinity of Yap Province of Micronesia. Five seamounts were selected for cobalt-rich crust survey in the eastern sea, and two in the western sea. Of these seven seamounts, four in the eastern sea are located in the EEZ of the Marshall Islands. These seamounts were selected after considering the water depth, size, and the survey itinerary.

The areal extent of the topographic survey differ by the size of the individual seamount, but it was generally 25 X 30 miles, which was an area sufficient for understanding the shape of the seamount and the topographic characteristics. For all seamounts, the survey provided detailed topography and formed the basis for sampling and other subsequent studies.

Table 7-1-1(1) Summary of Survey in Marshall Island Waters

Area	MS01	MS02	MS03	MS04	MS05	MS06	MS07	MS08	MS09	MS10	MS11	MS12	MS13
Location*1	14° 23′ N	14° 05′ N	14° 00′ N	14° 21′ N	11° 20′ N	13° 05′ N	12° 39′ N	13° 53′ N	16° 30′ N	12° 22′ N	10° 55′ N	8° 47′ N	8° 15′ N
	161° 02′ E	163° 11′ E	164° 02′ E	165° 50′ E	171° 05′ E	169° 26′ E	169° 29′ E	167° 31′ E	167° 10′ E	158° 38′ E	161° 27′ E	163° 12′ E	160° 40′ E
Duration of survey	6 days	6 days	5days	7days	6days	7days	1days	9days	5days	6days	6days	7days	7days
·Topographic survey										599.1nm	587.8nm	572.7nm	845.0nm
·SSS survey Number of track line				1		1		1		1	1	1	1
Total length of track line				10.0nm		5.4nm		11.8nm		5.1nm	6.9nm	7.3nm	5.4nm
·Sampling													
AD Number of samples	7	12	6	11	9	9	3	14	7	12	6	15	12
CB Number of samples											4		
LC Number of samples	7	6	6	4	4	4		4	6	3	3	3	3
Amount of crust samples (incl. Cobble crusts)	303.84kg	89.86kg	33.08kg	722.19kg	361.69kg	130.44kg	6.20kg	781.29kg	121.83kg	133kg	25kg	527kg	609kg
Amount of nodules	2.34kg	0.82kg	0.02kg	41.91kg	90.57kg	147.00kg	58.10kg	91.59kg	92.77kg	0.2kg	0.2kg	4kg	24kg
Amount of rocks & other material*3	67.73kg	41.42kg	72.41kg	249.15kg	149.88kg	18.59kg	4.02kg	20.17kg	76.69kg	131kg	41kg	202kg	191kg
·FDC observation Number of track line	1	1	1	2	2	2		2	1	1	1	2	2
Total length of track line	5.3nm	3.4nm	5.3nm	14.2nm	8.1nm	11.9nm		12.8nm	5.5nm	2.5nm	3.2nm	4.6nm	3.9nm
Number of photographs	310	175	340	756	55	593		689	435	150	142	172	192
Video tapes	3 reels	2 reels	3 reels	7reels	4reels	6reels		6reels	4reels	2reels	2reels	3reels	4reels
·Surveyed water depth zone													
Topographic·SBP survey	1,040~5,400m	1,330~5,600m	1,740~5,200m	980~5,200m	950~4,800m	1,580~5,700m	1,750~5,000m	1,350~4,300m	1,140~5,400m	1,292~5,100m	1,495~4,300m	1,037~5,100m	1,387~5,100m
Sampling	1,242~4,267m	1,527~3,219	2198~3,056m	1,039~3,140	950~4,620m	1,532~3,370m	2,169~2,546m	1,444~3,675m	1,170~4,265m	1,391~5,494m	1,690~4,353m	1,082~4,545m	1,801~4,069m
F D C	1,203~3,183m	1,489~1,573m	2006~3,995m	1,055~3,120m	1,269~3,206m	1,720~3,328m		1,488~3,376m	1,173~2,712m	1,396~2,816m	1,611~2,919m	1,066~2,564m	1,458~3,287m

*1: Center of seamount summits.

*2: 1998 survey is excluded because it was hydrothermal survey.

*3: Include coatings and stains.

Table 7-1-1(2) Summary of Survey in Marshall Island Waters

Area		MS01	MS02	MS03	MS04	MS05	MS06	MS07
Seamounts	Type	Guyot	Guyot	Guyot	Guyot	Pointed seamount	Guyot	Pointed seamount
	Scale (km) *4	70×60	60×50	>80×70	60×60	50×50	40×50	50×50
	Water depth distribution (m)	1,040~5,000m	1,330~5,500m	1,740m~	980~4,500m	950~4,800m	1,580~5,200m	1,750~4,900m
	Areal extent of summit	32×24km	38×16km	>80×70	20×16km	2.4×1.7km	18×12km	
	Slope inclination upper/middle/lower	26° /22° /10°	20° /19° /9°	10° /9°	17° /14° /9°	21° /21° /10°	25° /18° /11°	18° /16° /9°
	Summit~upper slope area (km²)	538	560	3,024	403	23	234	23.5
	Summit area (km²)	443	356	2,247	252	1.3	149	0.52
	Slope area (km²)	2,733	2,573	1,957	2,884	1,921	1,850	2,368
Geology	Summit	Basalt, basalt pyroclastics, basalt breccia	Basalt, basalt breccia, basalt pyroclastics, sandstone, limestone	Basalt, sandstone, limestone	Basalt, basalt pyroclastics, basalt breccia	Basalt, basalt pyroclastics, limestone, sandstone	Basalt, basalt breccia, basalt pyroclastics, mudstone, limestone, phosphate rock	Basalt, basalt pyroclastics
	Slope	Basalt, basalt pyroclastics, basalt breccia, limestone, mudstone	Basalt, basalt breccia, basalt pyroclastics, sandstone, limestone	Basalt, sandstone, limestone	Basalt, basalt breccia, basalt pyroclastics, sandstone, limestone	Basalt, basalt pyroclastics, limestone, phosphate rock, sandstone	Basalt, basalt breccia, basalt pyroclastics, mudstone, limestone, phosphate rock	Basalt, basalt pyroclastics, phosphate rock
	Mode & occurrence	Crusts, nodules mainly on summit periphery	Crusts, cobble crusts mainly on summit periphery	Crusts mainly on summit periphery	Crusts on summit periphery to middle slope	Crusts on summit, cobble crusts and nodules on slope	Crusts on summit	Crusts, nodules on upper slope and pinnacle slope
Cobalt rich crust	Substrate	Phosphate rocks	Breccia	Unknown	Basalt pyroclastics		Unknown	Unknown
Thickness	Thickness variation with water depth *5							
	Summit	24	23	38	8			
	Upper slope	40	27	17	12	23	30	17
	Middle slope	25	17		22	15	18	
	Lower slope	26			29	10		
	Average thickness (mm) *6	33	24	30	18	17	19	9
	Max. thickness (mm) *7	90	105	75	100	70	80	56
	Number of sampling site *8	11	16	7	13	9	10	3
Grade	Co (%)	0.66	0.74	0.67	0.84	1.00	0.83	0.84
	Ni (%)	0.64	0.58	0.56	0.52	0.70	0.57	0.63
	Cu (%)	0.13	0.10	0.13	0.08	0.11	0.09	0.12
	Mn (%)	22.70	23.06	22.22	23.45	26.29	24.16	24.96
	Fe (%)	14.35	14.71	14.00	14.84	13.21	14.79	14.35
	Number of samples assayed *9	18	23	10	23	18	17	8
	Mode of bedrock (crust) exposure	Outcrops are distributed at summit periphery and terrace steps. On the slope, they occur widely on the upper part as well as along the ridges of the middle part.	Outcrops are distributed widely from the summit periphery to upper slope. They are also observed on the western high of the summit	On the summit, outcrops are distributed on the northeastern terrace and the southwestern periphery. They are observed on the upper part of northern and	Outcrops are observed at the summit periphery, particularly a wide occurrence in the northern periphery. They occur on parts of the ridges of the slope.	Outcrops occur widely from the upper to middle slope.	On the summit, outcrops are distributed at the periphery and near pinnacles. On the slope, they are observed on parts of the ridges.	Outcrops are distributed long the NE-SW trending ridges.
	Assessment	Average thickness is high, and exposure ratio high.	Average thickness is rather high, and exposure ratio high.	Average thickness is rather high, but exposure ratio is low. Pt content is somewhat high.	Exposure ratio is high, and water depth shallow. Average thickness is rather low, but samples over 100mm thick have been collected.	Exposure ratio is high, and water depth low. Average thickness is rather low, and the sizes are small, thus the ore reserve is low.	Exposure are limited, and the average thickness is low.	Average thickness is rather low, but exposure ratio is high. Seamount is small and the water depth deep.

Area		MS08	MS09	MS10	MS11	MS12	MS13
Seamounts	Type	Guyot	Guyot	Guyot	Guyot	Guyot	Rugged guyot
	Scale (km) *4	130×100	70×70	22×20	28×45	40×30	25×50
	Water depth distribution (m)	1,350~5,000m	1,140~5,000m	1,292~5,600m	1,495~4,100m	1,037~4,900m	1,387~5,000m
	Areal extent of summit	55×35km	20×12km	18×13km	37×25km	26×21km	50×25km
	Slope inclination upper/middle/lower	7° /8°	21° /17° /7°	21° /18° /9°	14° /15° /8°	21° /18° /11°	14° /11° /8°
	Summit~upper slope area (km²)	2,521	212	206	876	462	1,916
	Summit area (km²)	1,074	145	134	670	235	1,122
	Slope area (km²)	4,692	4,035	455	1,232	929	1,417
Geology	Summit	Basalt, basalt breccia, basalt pyroclastics, phosphate rock, tuff	Basalt, basalt breccia, basalt pyroclastics	Basalt, foraminiferal calcareous conglomerate	Basalt	Basalt, foraminiferal calcareous conglomerate, reefal limestone	Basalt, foraminiferal calcareous conglomerate, tuff
	Slope	Basalt, basalt breccia, basalt pyroclastics, phosphate rock, sandstone, limestone	Basalt, basalt breccia, basalt pyroclastics, tuff, phosphate rock, limestone, mudstone	Basalt, foraminiferal calcareous conglomerate, tuff breccia	Basalt, foraminiferal limestone	Basalt, foraminiferal calcareous conglomerate, reefal limestone, tuff	Basalt, foraminiferal calcareous conglomerate, tuff
	Mode & occurrence	Crusts on summit periphery and near pinnacles	Crusts on summit. Nodules on both summit and slope	Crusts and cobble crusts from summit periphery to slope	Crusts from summit periphery to slope	Crusts from summit periphery to slope	Crusts and cobble crusts near pinnacles on summit
Cobalt rich crust	Substrate	Basalt	Lapilli tuff	Basalt, limestone, tuff breccia	Basalt, limestone	Basalt, limestone, tuff	Basalt, limestone
Thickness	Thickness variation with water depth *5						
	Summit	30	27	50	50	25	52
	Upper slope	13	22	26	15	75	2
	Middle slope	4	18	40	52	45	
	Lower slope	2	1	10			
	Average thickness (mm) *6	21	22	44	44	33	46
	Max. thickness (mm) *7	90	65	115	140	140	160
	Number of sampling site *8	18	12	13	7	16	12
Grade	Co (%)	0.74	0.70	0.69	0.69	0.67	0.50
	Ni (%)	0.55	0.68	0.47	0.48	0.57	0.39
	Cu (%)	0.10	0.14	0.05	0.05	0.05	0.04
	Mn (%)	22.95	23.28	21.08	21.73	23.88	20.75
	Fe (%)	14.56	13.40	14.42	14.91	14.40	16.87
	Number of samples assayed *9	29	20	14	8	15	11
	Mode of bedrock (crust) exposure	On the summit, outcrops are observed at the periphery, they occur particularly widely in a belt at the southern edge. On the slope, they are widely distributed on the	Outcrops are distributed widely from the summit periphery to the upper slope. Also rocks are exposed on the rim of the small depression at the southern part of the summit	On the summit, outcrops occur on the shoulder at the periphery. On the slope, they occur widely on the upper part.	On the summit, outcrops are observed at the periphery and near pinnacles. On the slope, they occur near pinnacles.	On the summit, wide exposures occur on the western side and the southern periphery. On the slope, outcrops occur in a wide area from the upper to middle part.	Outcrops occur near the summit pinnacles.
	Assessment	Thick crusts are limited to the summit and exposure ratio low, but the seamount is large and thus the amount of crusts is large.	The seamount is relatively small, but the exposure ratio is high, average thickness relatively high, and the water depth relatively shallow.	Co,Ni grade are high. Thick crust distributing on from marginal part to middle part of slope.	Co,Ni grade are high and crust thickness is very thick.	Co,Ni grade are high and crust thickness is very thick.	Co,Ni grade are a little low but thick crust distributing.

*4: For 1996 survey areas (MS01~09), the values indicate "long axis x short axis" of the water-depth contour of the base. For 1998 survey areas (MS10~13), the values indicate the "long axis x short axis" of the 3,000m water-depth contour
*5: For 1996 survey area (MS01~09), the average of the thickness of assayed samples. For 1998 survey areas (MS10~13), the average value of the average   *6: Average of all collected samples *7: Maximum value of all collected samples, excluding nodules in (MS10~13).
*8: Sampling sites where crusts, cobble crusts, and nodules were collect *9: Number of assayed samples

All four seamounts are guyots, and three have dome-type summit, one with undulating rugged summit.

The water depth of the shallowest seamount summits ranges from 1,037m to 1,495m, the relative height from the base ranges from 2,700m to 4,300m and the seamount of the MS10 area is the smallest with seamount area of 22 X 20km and summit area of 134km^2 ; and the largest seamount is MS11 occupying an area of 28 X 45km. The largest summit area is that of MS13 with 1,122km^2.

(MBES acoustic reflection intensity)

The seamounts in the three areas MS10~12 are guyots with dome-shaped summits. The summit of these seamounts are all covered by unconsolidated sediments and thus pale color tone indicating low acoustic reflection intensity extends over the entire summit. At pinnacles and peripheral parts of the summit, however, dark tones appear. Also in these seamounts, dark parts of the images are distributed from the summit periphery to the upper slope. Particularly the seamount in the MS12 area has a relatively wide occurrence of exposed rocks even in the middle slope.

The seamount in area MS13 which is a guyot but with rugged summit, generally show pale color on the summit, but dark colored parts are conspicuous corresponding to the many pinnacles in the central part.

The bedrock exposures of seamounts are often covered by cobalt-rich crust, and thus the dark parts corresponding to exposed bedrocks indicate the possibility of cobalt-rich crust distribution. In the present survey area, cobalt-rich crust samples were collected from the dark-colored parts of all areas.

(SBP survey)

The three seamounts in MS10, MS11, MS12 areas, all tend to have thicker unconsolidated sediments toward the central part of the summit, particularly the central part of the summit of the seamount in MS12 area is covered by more than 120m of unconsolidated sediments. In these seamounts, the MBES acoustic reflection intensity indication of rock exposures from summit periphery to the upper slope is also confirmed by SBP survey. The MBES acoustic reflection intensity shows the existence of exposed rocks to the middle slope in the seamount in the MS12 area, but SBP survey indicates that the unconsolidated sediments are generally thin in areas where bedrocks are not exposed.

The summit and slope of the seamount in MS13 area are covered by thick unconsolidated sediments, but exposure of acoustic basement was observed in the central part of the summit corresponding to pinnacles and many other protrusions.

(SSS survey)

SSS survey was carried out on the terraces which occur in the summit peripheries of the seamounts with dome-shaped summit in areas MS10~MS13. The results showed the occurrence of pebbles on the terraces regardless of the existence of unconsolidated sediments. Many cobble crusts were recovered from the terrace of the seamount in MS10, and similar cobble crusts have been sampled from the summit peripheries of other seamounts. Thus the pebbles confirmed by SSS survey are most probably cobble crusts.

In the MS13 area seamount, SSS survey was carried out in the depressions between the pinnacles in the summit center. It was confirmed that the distribution of the unconsolidated sediments is local not only in the protrusions but also in the depression, and that exposures occur widely.

(Sampling)

Sampling by dredges and a large corer was carried out at 61 sites in four areas, MS10 to MS13. Cobalt-rich crusts were recovered from 51 sampling points, of which crusts or cobble crusts were collected from 48 points, and nodules were recovered from three points by large corer. Ores from 48 samples from 43 sites were assayed. One sample was analysed by EPMA. Also representative samples of rocks and bottom sediments and those which were considered to be necessary for assessing the occurrence of cobalt-rich crusts were studied microscopically, chemically analysed, and fossils identified.

(Geology)

The rocks collected from the four areas, MS10~MS13, were basalt, limestones, tuffaceous rocks, hyaloclastite, and pumice.

In all seamounts, basalt and limestone occur from the summit to the slope.

The lithology of the basalt differs somewhat by the seamount, but majority are aphyric or those with minute phenocrysts. Basalt is strongly weathered in all seamounts, and fresh samples were not obtained.

Conglomerate samples with foraminiferal limestone matrix containing foraminiferal limestone and basalt pebbles were recovered from the summit to the slope of each seamount. In MS11 seamount, however, occurrence of limestone is not confirmed on the summit. From MS12 seamount, reefal limestone samples indicating the formation of coral reef were collected from the summit. And from MS11 seamount, although reefal limestone samples were not recovered, fragments of reef-building corals were confirmed in the tuff samples collected from the upper slope.

Occurrence of tuff and tuff breccia are confirmed in all seamounts, but their distribution is heterogeneous, and wide occurrence such as seen in basalt and limestone is not observed. Hyaloclastite samples were collected near the pinnacles in summit center of MS13 seamount, and some from the upper slope of MS12 seamount.

Pumice samples were collected from various localities of the survey area.

(Seafloor observation)

Seafloor was observed by FDC along six track lines in four areas. In all seamounts, crust occurrence was confirmed in exposed zones over wide areas from the summit peripheries to the upper slopes. Sedimentary cover was observed in many localities at summit periphery of MS11 area and at upper slope terrace of MS13 area, but cobble crusts and nodules were distributed on the sediments.

In MS10 area, angular fragments believed to be talus were observed at the steep part of the slope. But in this seamount, cobble crusts were seen to be mixed with angular fragments. Angular fragment cover was also observed in seamount slope of the MS12 area, but the exposed parts were confirmed to be covered by crusts.

(Thickness of cobalt-rich crusts)

Thick crusts occur on each seamount. The average thickness of the samples recovered from each seamount ranges from 33.1mm to 46.4mm, and the maximum thickness of the samples of each seamount exceeds 100mm. Particularly in the MS10~MS12 areas, crusts with average thicker than 20mm occur from the summit peripheries to the slopes. The crusts in MS10 and MS11 areas tend to be somewhat thinner on the slopes than on the summit periphery, but those on MS12 seamount have similar thickness, and thick crusts have been recovered from both zones.

In MS13 area, the occurrence of thick crusts are limited to parts of northwestern periphery of the summit, but crusts and cobble crusts thicker than 100mm occur near the pinnacles in the central part of the summit.

(Chemical analysis of cobalt-rich crusts)

Forty-eight cobalt-rich crust samples were selected from those collected at 43 sites in four areas of

MS10~13. They were chemically analyzed.. Total number of analysis including those with layer analysis was 106 samples. The average grade of the major elements are; CoO 0.6%, NiO 0.48%, Cu 0.05%, Mn 22.85%, Fe 13.4%. The variation of Co, Ni, Cu grades of the MS10~MS12 areas are small, but those of MS13 area are low. Compared with those of MS01~MS09 areas surveyed in 1996, the contents of four major elements and Pt, excluding Fe, are somewhat lower in MS10~MS13 areas and areal difference is observed.

EPMA analysis was carried out for one sample from MS10 area. It was observed that Co and Ni contents increases outward from the inner layer. This tendency was observed in the crusts from MS01~MS09 areas. In one of the samples analyzed, texture with metallic luster was observed. This texture differs from common sea water-origin manganese nodules and cobalt-rich crusts.

(Conditions of cobalt-rich crust occurrence)

As a result of sampling, the occurrence of thick crusts and cobble crusts with average exceeding 30mm and maximum of over 100mm was confirmed in all four areas.

The crusts are exposed widely on the upper slope of the seamount in MS10 area. But the thick crusts are concentrated to near the periphery. In MS11 area, crust exposure is restricted to the summit periphery and parts of the slope and the exposure ratio is low, but the size of the seamount is large and the exposed area is large. In MS12 seamount, more than 20mm thick crusts are widely distributed from the summit periphery to the middle slope. In MS13 seamount, the exposure ratio is generally low, and thick crusts are limited to the vicinity of the pinnacles which occur sporadically on the summit.

Assessment of each area on the basis of the crust occurrence would be; MS11 and MS12 areas are most promising followed by MS10 area. But the difference among the three areas is small. MS13 area is low in reserved and metal grade compared to MS10~MS12 seamounts.

(Discussions)

The seamounts surveyed this year in MS10~MS13 areas were formed before Paleogene and thick crusts were confirmed in all four areas. The three seamounts in MS10~MS12 areas are guyots with dome-shaped summit and there are many similarities in cobalt-rich crust occurrence including geology and metal content. Also regarding the seamounts in MS01~MS09 areas which were surveyed in 1996, thick cobalt-rich crusts were collected from the guyots formed before Paleogene. In the waters of the Republic of the Marshall Islands, there are many unexplored pre-Paleogene seamounts, and occurrence of thick cobalt-rich crusts on these seamounts is highly possible. Future investigation is most desirable. Compared to the seamounts surveyed in

1996, those of the present survey tend to have thicker crusts but somewhat lower metal grade. Presently available data are insufficient to consider if this tendency can be generalized in this area, and further acquisition of data is necessary and important.

The area surveyed during 1996 and the present project comprises approximately the northwestern half of the EEZ of the Republic of Marshall Islands, and the distribution of seamounts and the conditions of cobalt-rich crust occurrence in the area are as follows.

The results of sampling and seafloor observation show that crusts thicker than 10cm occur at 1,000~3,500m water depth. Cobalt-rich crusts take the forms of; crusts, cobble crusts, and nodules. Their thickness varies by areas, topography, and substrates. The average thickness of the crusts by seamounts tends to be thicker to the west and the metal grade higher to the east. This tendency, however, is observed but is not clear- cut.

In assessing the potential of each area by the occurrence of the crusts; the seamounts in the western part of the area surveyed this year are most promising, followed by the seamounts continuing to the northern part of the Ralik Chain. This is due to the thick crusts in the western side and the high grade in the eastern side.

In the water where the suvey had been carried out, the relation between the thickness and grade of cobalt-rich crust and the age of seamounts is recognized, thus it is suggested the possibirity to understand the conditions of cobalt-rich crust occurrence in the whole of the EEZ of the Republic of Marshall Islands, on codition that further acquisition of data.

[REFERENCES]

Bonani G., Hofmann H.J., Morenzoni E., Nessi M., Suter M., and Wolfli W, 1984, ^{10}Be dating of the inner structure of Mn-encrustations applying the Zurich Tandem Accelerator, Nuclear Instruments and Methods in Physics Research B5, 359-364

Brevart O., B. Dupre and C.J. Allegre, 1981, Metallogenesis at spreading centers; lead isotope systematics for sulfides, manganese-rich crusts, basalts and sediments from Cyamax and Alvin areas (East Pacific Rise). Econ. Geol. Bull. Soc. Econ. Geologists., 76, 5, p. 1205-1210.

De Carlo E.R. and C.M. Fraley, 1992, Chemistry and mineralogy of ferromanganese deposits from the equatorial Pacific Ocean., Geology and offshore mineral resources of the central Pacific basin, p. 225-245.

Hart S., 1984, A large scale anomaly in the Southern Hemisphere mantle. Nature 309, 753-757.

Haynes B.W. and M.J. Magyar, 1987, Analysis and metallurgy of manganese nodules and crusts., Marine Minerals, p. 235-246.

Hein J.R., M.S. Schulz, and L.M. Gein, 1992, Central Pacific cobalt-rich ferromanganese crusts: Historical perspective and regional variability., Geology and offshore mineral resources of the central Pacific basin, p. 261-283.

Hein J.R., W.C. Schwab and A.S. Davis, 1988, Cobalt-and Platinum-rich ferromanganese crusts and associated substrate rocks from the Marshall islands., Marine Geology, v.78, p. 255-283.

Hein J.R. et al., 1990, Geological, Geochemical, Geophysical, and Oceanographic Data and Interpretations of Seamounts and Co-rich Ferromanganese Crusts from the Marshall Islands, KORDIUSGS R.V. Farnella Cruise F10-89-CP.

Janney P.E. and P.R. Castillo, 1996, Basalts from the central Pacific basin: Evidence for the origin of Cretaceous igneous complexes in the Jurassic western Pacific., vol.101, no. B2, p. 2875-2893.

JICA-MMAJ, 1997, Report on the cooperative study project on the deepsea mineral resources in selected offshore areas of the SOPAC region sea area of the Republic of the Marshall Islands, P.180

Lincoln J., M.S. Prigle and I.P. Silva, 1993, Early and late Cretaceous volcanism and reef-building in the Marshall Island. in The Mesozoic Pacific; Geology, Tectonics, and Volcanism., Geophysical Monograph 77.

Mangini A., P. Halbach, D. Puteanus, and M. Segl, 1987, Chemistry and growth history of central Pacific Mn-crusts and their economic importance., Marine Minerals, p. 205-220.

Mullen E.D., 1983, $MnO/TiO_2/P_2O_5$:a minor element discriminant for basalt rocks of oceanic enviroments and its implications for petrogenesis. Earth Planet. Sci. Lett., 62, 53-62.

Sharma P. and B.L.K. Somauajulu, 1982, 10Be dating of large manganese nodules from world oceans., Earth ahronology, Earth Planet. sci. Let., v.36, p. 359-362.

KORDI-USGS (Hein J.R. et al.), 1992, Geology, Geophysics, Geochemistry, and Deep-Sea Mineral Deposits, Federated States of Micronesia: R.V.Farnella Cruise F11-90-CP, USGS Open File Report 92-218.

Usui A., 1995, Studies of marine manganese deposits: Review and perspectives., Chishitsu News, no. 493, p. 30-41. (Japanese)

Verma S.P., 1992, Seawater alteration effects on REE, K, Rb, Cs, Sr, U, Th, Pb and Sr-Nd-Pb isotope systematics of Mid-ocean ridge basalt. Geochem. Jour., 36, 159-178.

Woodhead J.O. and C.W. Devey, 1993, Geochemistry of the Pitcairn seamounts, I: source character and temporal trends. Earth Planet. Sci. Left., 116, 81-99.

Zindler A. and S. Hart, 1986, Chemical geodynamics. Ann. REv. Earth Planet. Sci., 14, 493-571.

[**Appendix**]

Appendix Table 1 (1) Summary of Sampling Results

No.	Sample No.	Sampling site: Latitude	Sampling site: Longitude	MBES Depth(m)	CTD-BT Depth(m)	CTD-BR Depth(m)	Topographic division	Crust type	Amount of samples(kg)	LC core length (cm)	Crust thickness (mm) Max	Min	Av.	Type of substrates, nuclei.	Type of rocks・rock fragments bottom sediments (LC)
1	98SMS10LC01	12° 26.012′ N	158° 22.036′ E	5,494	5,516	5,509	Lower western slope	Nodule	0.13	352	17	7	10		Brown clay (photo:nodule)
2	98SMS10AD02	12° 19.806′ N	158° 34.551′ E	1,577	1,599	1,428	Upper western slope	Crust, crust fragment	0.03	–	28	18	22		
3	98SMS10AD03	12° 23.811′ N	158° 34.329′ E	1,765	1,770	1,660	Upper western slope	Crust	1.63	–	60	10	15	Basalt.	Basalt, tuff.
4	98SMS10AD04	12° 23.965′ N	158° 39.901′ E	2,062	2,023	1,812	Middle northern slope	Crust	7.28	–	18	–	10	Tuff breccia, basalt, limestone.	Tuff breccia, basalt, limestone.
5	98SMS10AD05	12° 23.535′ N	158° 39.957′ E	1,506	1,445	1,403	Middle northern slope	Crust	0.29	–	24	2	18	Basalt.	Foraminiferal limestone, basalt.
6	98SMS10AD06	12° 16.920′ N	158° 36.949′ E	2,092	2,094	1,847	Middle southern slope	Crust fragment.	0.37	–	23	9	15		Pumice.
7	98SMS10AD07	12° 17.008′ N	158° 37.101′ E	1,701	1,728	1,626	Upper southern slope	Crust fragment.	1.22	–	32	5	21		
8	98SMS10AD08	12° 17.999′ N	158° 40.212′ E	1,457	1,415	1,391	South summit periphery	Cobble crust, crust.	95.99	–	100	3	51	conglomerate.	
9	98SMS10AD09	12° 17.006′ N	158° 40.360′ E	2,122	2,081	1,865	Middle southern slope	Cobble crust.	19.67	–	130	42	60		Basalt, pumice.
10	98SMS10AD10	12° 19.694′ N	158° 33.673′ E	2,070	2,005	1,872	Middle western slope	Crust fragment.	0.65	–	22	8	18		
11	98SMS10AD11	12° 16.310′ N	158° 40.556′ E	2,438	2,435	2,250	Middle southern slope	Crust fragment.	0.04	–	16	5	10.0		Pumice.
12	98SMS10AD12	12° 18.763′ N	158° 42.207′ E	2,103	2,097	1,866	Middle eastern slope	Crust fragment.	1.37	–	46	7	25		
13	98SMS10LC13	12° 19.800′ N	158° 41.046′ E	1,433	1,412	1,401	Eastern summit periphery	Crust fragment attached.	0.03	0					Not collected (photo:foraminiferal sand)
14	98SMS10LC14	12° 20.295′ N	158° 34.772′ E	1,488	1,468	1,458	Western summit periphery		0.00	78					Foraminiferal sand (photo:foraminiferal sand)
15	98SMS10AD15	12° 21.240′ N	158° 34.334′ E	1,426	1,409	1,384	Western summit periphery	Crust fragment.	4.59	–	50	10	25		Pumice.
16	98SMS11LC01	10° 53.958′ N	161° 04.991′ E	4,353	–	–	Lower western slope			226				Calcareous clay (partly foraminiferal sand)	Calcareous clay (partly foraminiferal sand)
17	98SMS11CB02	10° 47.989′ N	161° 22.620′ E	2,057	2,034	1,928	Western summit periphery	Cobble crust, crust fragment.	17.88		110	7	48	Basalt	
18	98SMS11CB03	10° 47.581′ N	161° 22.248′ E	2,387	2,381	2,036	Upper western slope	Crust fragment.	0.26		20	2	5		
19	98SMS11CB04	10° 47.567′ N	161° 29.945′ E	1,869	1,841	1,664	Eastern summit periphery	Not collected.							Pumice.
20	98SMS11CB05	10° 56.283′ N	161° 22.076′ E	1,844	1,818	1,698	Western summit periphery.	Crust fragment.	0.00		–	–	–		
21	98SMS11AD06	10° 54.178′ N	161° 20.373′ E	2,373	2,374	2,109	Eastern summit periphery	Crust.	2.48		35	5	10	Limestone, basalt.	Limestone, basalt, pumice.
22	98SMS11AD07	10° 59.753′ N	161° 21.744′ E	2,089	2,077	1,956	Western summit periphery	Crust fragment.	2.21		50	20	30		Basalt.
23	98SMS11AD08	10° 48.399′ N	161° 31.955′ E	1,991	1,952	1762	Eastern summit periphery	Crust fragment, crust	2.64		90	5	20	Basalt.	Basalt.
24	98SMS11AD09	10° 53.415′ N	161° 36.170′ E	2,614	2,515	2,447	Eastern summit periphery	Crust, crust fragment.	10.33		140	20	100	Basalt, limestone.	Basalt.
25	98SMS11AD10	11° 05.200′ N	161° 26.400′ E	2,673	2,667	2,468	Middle northern slope	Crust fragment, nodule	0.26		20	2	5	Phosphorite.	
26	98SMS11LC11	10° 57.253′ N	161° 31.963′ E	1,690	1,670	1,665	Eastern summit periphery		0.00	0					Not collected (photo:crust)
27	98SMS11LC12	10° 54.480′ N	161° 32.865′ E	1,867	1,846	1,831	Eastern summit periphery		0.00	0					Not collected (photo:sand, crust.)
28	98SMS11AD13	10° 44.755′ N	161° 25.156′ E	2,042	1,921	1,928	Southern summit periphery	Crust fragment.	0.01						

Appendix Table 1 (2) Summary of Sampling Results

No.	Sample No.	Sampling site: Latitude	Sampling site: Longitude	MBES Depth(m)	CTD-BT Depth(m)	CTD-BR Depth(m)	Topographic division	Crust type	Amount of samples (kg)	LC core length (cm)	Crust thickness (mm) Max	Min	Av.	Type of substrates, nuclei.	Type of rocks・rock fragments bottom sediments (LC)
29	98SMS12LC01	8° 48.006′ N	163° 30.030′ E	4, 545	4,528	4,521	Foot of eastern slope	Nodule.	0.57	335	22	7	10	Phosphorite, basalt.	Pale brown clay.
30	98SMS12AD02	8° 44.310′ N	163° 08.542′ E	1, 547	1,554	1,386	Upper western slope	Crust, crust fragment.	41.52		40	0	23	Conglomerate.	limestone, basalt, pumice.
31	98SMS12AD03	8° 42.977′ N	163° 12.584′ E	1, 573	1,555	1,373	Upper southern slope	Crust.	4.37		55	5	28	Basalt.	Conglomerate, basalt, pumice.
32	98SMS12AD04	8° 42.210′ N	163° 14.860′ E	1, 990	1,974	1,857	Upper southern slope	Crust.	3.42		47	3	10	Basalt, tuff breccia.	Basalt, tuff breccia.
33	98SMS12AD05	8° 42.310′ N	163° 14.844′ E	1, 739	1,719	1,639	Upper southern slope	Crust.	5.64		85	1	9	Limestone.	Pumice, basalt.
34	98SMS12AD06	8° 47.695′ N	163° 06.547′ E	1, 719	1,689	1,487	Upper western slope	Crust fragment.	0.09		10	1	6		Limestone, basalt, pumice.
35	98SMS12AD07	8° 47.495′ N	163° 07.244′ E	1, 444	1,448	1,250	Upper western slope	Cobble crust.	194.80		140	1	44	Tuff breccia.	
36	98SMS12AD08	8° 49.465′ N	163° 04.980′ E	2, 054	2,060	1,892	Middle western slope	Crust, crust fragment.	17.88		96	5	34	Limestone.	Pumice.
37	98SMS12AD09	8° 48.761′ N	163° 05.804′ E	1, 775	1,796	1,424	Upper western slope	Crust fragment, nodule.	0.85		22	1	11	Basalt, tuff, limestone.	Pumice.
38	98SMS12AD10	8° 49.602′ N	163° 05.826′ E	1, 553	1,499	1,438	Upper western slope	Crust.	1.02		62	1	19	Basalt.	Pumice.
39	98SMS12AD11	8° 51.453′ N	163° 08.759′ E	1, 405	1,342	1,260	Upper northern slope	Crust, crust fragment, cobble crust.	6.64		60	7	39	Hyaloclastite.	Pumice.
40	98SMS12AD12	8° 52.636′ N	163° 11.679′ E	2, 114	1,983	2,039	Middle northern slope	Crust, crust fragment.	1.20		21	0	10	Basalt.	Basalt, pumice.
41	98SMS12AD13	8° 52.049′ N	163° 11.715′ E	1, 707	1,716	1,497	Upper northern slope	Crust.	26.95		53	1	20	Limestone, basalt.	Basalt, pumice.
42	98SMS12LC14	8° 45.035′ N	163° 12.464′ E	1, 177	1,130	1,121	Summit			−					Foraminiferal sand.
43	98SMS12LC15	8° 43.616′ N	163° 16.045′ E	1, 383	1,372	1,360	Eastern summit periphery			0					limestone, basalt, pumice.
44	98SMS12AD16	8° 39.587′ N	163° 07.930′ E	2, 318	2,268	2,054	Middle southern slope	Crust, cobble crust, crust fragment.	67.70		90	18	31	Basalt, conglomerate, limestone.	Basalt, conglomerate.
45	98SMS12AD17	8° 42.911′ N	163° 10.270′ E	1, 325	1,273	1,279	Southern summit periphery	Cobble crust, nodule.	118.18		96	0	32	Basalt, conglomerate.	
46	98SMS12AD18	8° 44.322′ N	163° 11.676′ E	1, 189	1,157	1,097	Summit	Crust, nodule.	1.62		27	1	14	Tuff, limestone.	Tuff.
47	98SMS13LC01	8° 18.070′ N	160° 25.125′ E	4, 069	4,029	4,021	Lower western slope	Nodule.	0.24	215	15	6	10	Basalt, tuff.	Calcareous clay (poto:sand, nodule)
48	98SMS13AD02	8° 19.567′ N	160° 35.806′ E	1, 927	1,912	1,799	Western summit	Crust, nodule.	0.26		22	1	6	Basalt.	Basalt, tuff, limestone.
49	98SMS13AD03	8° 18.503′ N	160° 31.694′ E	2, 524	2,527	2,200	Western summit	Crust, cobble crust, nodule.	220.99		40	1	10	Basalt, phosphorite.	Basalt, pumice.
50	98SMS13AD04	8° 15.237′ N	160° 30.240′ E	2, 859	2,901	2,333	Upper western slope								Basalt, tuff breccia, limestone, pumice.
51	98SMS13AD05	8° 11.657′ N	160° 33.630′ E	2, 033	−	−	Western summit	Crust, nodule.	145.58		100	1	28	Basalt, calcareous	Calcareous conglomerate, basalt,
52	98SMS13AD06	8° 09.509′ N	160° 31.878′ E	2, 334	2,289	2,082	Western summit	Crust, cobble crust, nodule.	46.96		160	1	100	Basalt.	Basalt.
53	98SMS13AD07	8° 05.486′ N	160° 29.286′ E	2, 513	2,469	2,120	Southwest summit	Crust, cobble crust, nodule.	161.92		100	5	68	Calcareous conglomerate.	Pumice.
54	98SMS13AD08	8° 03.827′ N	160° 31.617′ E	2, 077	2,054	1,927	Southwest summit	Crust, cobble crust.	11.20		60	10	30	Basalt.	Pumice.
55	98SMS13AD09	8° 11.470′ N	160° 34.599′ E	1, 861	1,837	1,816	Central summit	Crust, cobble crust, nodule.	37.85		60	5	29	Basalt, limestone, phosphorite.	Foraminiferal sand.
56	98SMS13AD10	8° 10.239′ N	160° 36.793′ E	2, 359	2,333	2,211	Eastern summit	Crust fragment, nodule.	1.73		30	1	14	Basalt, phosphorite.	Basalt, pumice.
57	98SMS13LC11	8° 12.821′ N	160° 36.989′ E	2, 029	2,005	2,002	Eastern summit			0					
58	98SMS13LC12	8° 11.959′ N	160° 33.343′ E	2, 079	2,082	2,077	Western summit			0					
59	98SMS13AD13	8° 24.140′ N	160° 35.906′ E	2, 509	2,464	2,439	Northwest summit	Crust.	5.29		25	2	8	Basalt, limestone.	Basalt, pumice.
60	98SMS13AD14	8° 27.022′ N	160° 39.972′ E	2, 813	2,746	2,785	Upper northern slope	Crust.	0.70		5	1	2	Basalt.	Pumice.
61	98SMS13AD15	8° 28.293′ N	160° 46.138′ E	3, 120	−	−	Upper northern slope	Crust.	0.07		3	1	1	Limestone.	Pumice.

Appendix Table 2 (1) Rock Samples from MS10 Area

Sample number	Rock type	Water depth (m)		Substrate	Description
		On bottom	Off bottom		
98 AD 08	Substrate rock of Cobble crust	1,415	1,391	Basalt	Subangular cobbles of aphyric basalt.
AD 08	Substrate rock of Cobble crust	1,415	1,391	Basalt	Angular cobbles of aphyric porous basalt.
AD 08	Substrate rock of Cobble crust	1,415	1,391	Basalt	Angular cobbles of phyric porous basalt.
AD 08	Substrate rock of Cobble crust	1,415	1,391	Calcareous conglomerate	Pebbles; subangular～subrounded aphyric basalt. Matrix phosphatized.
AD 08	Substrate rock of crust	1,415	1,391	Calcareous conglomerate	Pebbles; subrounded aphyric basalt.
AD 08	Substrate rock of Cobble crust	1,415	1,391	Calcareous conglomerate	Pebbles; subrounded phyric and aphyric basalt.
AD 08	Substrate rock of Cobble crust	1,415	1,391	Basalt	Subrounded cobbles of phyric vitreous basalt.
AD 08	Substrate rock of Cobble crust	1,415	1,391	Calcareous conglomerate	Pebbles; subangular phyric vitreous basalt. Matrix phosphatized.
AD 05	Substrate rock of crust	1,445	1,403	Basalt	Phyric (acicular plagioclase) vitreous.
AD 05	Rock	1,445	1,403	Basalt	Aphyric・porous.
AD 05	Rock	1,445	1,403	Calcareous conglomerate	Contain flat pebbles of phyric vitreous basalt.
AD 03	Substrate rock of crust	1,770	1,660	Basalt	Phyric・porous.
AD 03	Substrate rock of crust	1,770	1,660	Basalt	Phyric・vitreous.
AD 03	Rock	1,770	1,660	Basalt	Phyric・porous.
AD 03	Rock	1,770	1,660	Basalt	Phyric・vitreous.
AD 03	Rock	1,770	1,660	Tuff	Pumiceous.
AD 04	Substrate rock of crust	2,023	1,812	Tuff breccia	Matrix; basaltic tuff, contain angular～subangular pebbles of aphyric・phyric basalt.
AD 04	Substrate rock of crust	2,023	1,812	Tuff breccia	Matrix; basaltic tuff, contain angular～subangular pebbles of aphyric・phyric basalt.
AD 04	Substrate rock of crust	2,023	1,812	Basalt	Aphyric, vitreous.
AD 04	Substrate rock of crust	2,023	1,812	Basalt	Aphyric, vitreous.
AD 04	Substrate rock of crust	2,023	1,812	Tuff breccia	Basaltic.
AD 04	Substrate rock of crust	2,023	1,812	Limestone	2 types, white and brownish gray.
AD 04	Rock	2,023	1,812	Basalt	Minute acicular plagioclase crystals are distributed.
AD 04	Rock	2,023	1,812	Tuff breccia	Matrix; basaltic tuff, contain angular pebbles of aphyric vitreous basalt.
AD 04	Rock	2,023	1,812	Limestone	Weathered, fragile.
LC 01	Substrate rock of Nodule	5,516		Phosphorite	Pink, compact, hard.

Appendix Table 2 (2) Rock Samples from MS11 Area

Sample number	Rock type	Water depth (m)		Substrate	Description
		On bottom	Off bottom		
98 AD 08	Substrate rock of Cobble crust	1,937	1,747	Basalt	Fine grained. Aphyric.
AD 08	Rock	1,937	1,747	Basalt	Vitreous. Aphyric.
CB 02	Substrate rock of Cobble crust	2,019	1,912	Basalt	Fine grained. Phyric.
CB 02	Substrate rock of Cobble crust	2,019	1,912	Limestone	Hard by phosphatization.
CB 02	Substrate rock of Cobble crust	2,019	1,912	Basalt	Fine grained, phyric. Acicular plagioclase crystals notable.
AD 07	Rock	2,062	1,941	Basalt	Porous, aphyric.
CB 06	Substrate rock of Cobble crust	2,359	2,094	Limestone	Pelitic, soft, contain micronodules.
CB 06	Substrate rock of Cobble crust	2,359	2,094	Basalt	Fine grained, compact, rare occurrence of acicular plagioclase crystals.
CB 06	Substrate rock of Cobble crust	2,359	2,094	Basalt	Fine grained, compact, rare occurrence of acicular plagioclase crystals.
CB 06	Substrate rock of Cobble crust	2,359	2,094	Basalt	Fine grained, compact, phyric.
CB 06	Rock	2,359	2,094	Basalt	Fine grained, compact, phyric.
CB 06	Rock	2,359	2,094	Limestone	Pelitic, soft, contain micronodules.
AD 09	Substrate rock of Cobble crust	2,500	2,462	Basalt	Fine grained, compact, rare occurrence of acicular plagioclase crystals.
AD 09	Substrate rock of Cobble crust	2,500	2,462	Limestone	Pelitic, soft, contain basalt fragments.
AD 09	Rock	2,500	2,462	Basalt	Fine grained, phyric.
AD 10	Substrate rock of Nodule	2,652	2,453	Phosphorite	Hard, contain micronodules.

Appendix Table 2 (3) Rock Samples from MS12 Area

Sample number	Rock type	Water depth (m)		Substrate	Description
		On bottom	Off bottom		
98 AD 18	Crust	1,142	1,082	Tuff	Soft, Mn stains.
AD 18	Substrate rock of Nodule	1,142	1,082	Limestone	Hard by phosphatization.
AD 17	Substrate rock of Cobble crust	1,258	1,264	Calcareous Conglomerate	Contain angular basalt pebbles. Biogenic fragments.
AD 17	Substrate rock of Cobble crust	1,258	1,264	Basalt	porous, subrounded cobbles. From nuclei together with two rocks below.
AD 17	Substrate rock of Cobble crust	1,258	1,264	Calcareous Conglomerate	Contain rounded basalt pebbles. Hard by phosphatization.
AD 17	Substrate rock of Cobble crust	1,258	1,264	Tuff	Greenish gray. Alteration significant.
AD 17	Substrate rock of Cobble crust	1,258	1,264	Tuff	Fine grained homogeneous.
AD 17	Substrate rock of Nodule	1,258	1,264	Basalt	Phyric, porous.
AD 11	Substrate rock of crust	1,327	1,245	Hyaloclastite	Matrix vitreous, basalt pebbles, generally altered to brown.
AD 11	Substrate rock of Cobble crust	1,327	1,245	Basalt	Aphyric, porous.
AD 07	Substrate rock of Cobble crust	1,433	1,235	Limestone	Fine grained, compact, hard. Homogeneous, not phosphatized.
AD 07	Substrate rock of Cobble crust	1,433	1,235	Basalt	Fine grained, aphyric. Form agglomeratic host together with the rock below.
AD 07	Substrate rock of Cobble crust	1,433	1,235	Hyaloclastite	Matrix vitreous, basalt and pumice pebbles.
AD 07	Rock	1,433	1,235	Basalt	Aphyric, porous.
AD 10	Substrate rock of crust	1,484	1,423	Basalt	Phyric, porous. Transparent minerals abundant.
AD 02	Substrate rock of crust	1,539	1,371	Calcareous Conglomerate	Contain abundant subangular~subrounded basalt pebbles.
AD 02	Substrate rock of crust	1,539	1,371	Calcareous Conglomerate	Contain subangular~sabrounded basalt pebbles. Intercalations of white soft calcite.
AD 02	Substrate rock of crust	1,539	1,371	Calcareous Conglomerate	Contain subrounded basalt pebbles. Hard by phosphatization.
AD 02	Rock	1,539	1,371	Calcareous Conglomerate	Contain angular basalt pebbles.
AD 03	Substrate rock of crust	1,540	1,358	Basalt	Phyric, vitreous, strongly weathered.
AD 03	Rock	1,540	1,358	Basalt	Phyric, vitreous, strongly weathered, partly argillized
AD 03	Rock	1,540	1,358	Calcareous Conglomerate	Contain angular basalt pebbles.
AD 06	Rock	1,674	1,472	Limestone	phosphatized, hard.
AD 06	Rock	1,674	1,472	Basalt	Small fragments.
AD 13	Substrate rock of crust	1,701	1,476	Calcareous Conglomerate	Fine grained, partly vesicular, contain subrounded~rounded basalt pebbles.
AD 13	Substrate rock of crust	1,701	1,476	Basalt	Aphyric, porous.
AD 13	Substrate rock of crust	1,701	1,476	Basalt	Fine grained, aphyric.
AD 05	Substrate rock of crust	1,704	1,624	Reefal Limestone	Coarse grained, porous, spongy, hard by phosphatization.
AD 05	Rock	1,704	1,624	Basalt	Aphyric, porous.
AD 09	Substrate rock of Nodule	1,781	1,409	Basalt	Aphyric, porous.
AD 09	Substrate rock of Nodule	1,781	1,409	Basalt	Fine grained, compact, aphyric.
AD 09	Substrate rock of Nodule	1,781	1,409	Hyaloclastite	
AD 09	Substrate rock of Nodule	1,781	1,409	Limestone	Abundant biological fragments.
AD 04	Substrate rock of crust	1,959	1,842	Tuff breccia	Matrix pumiceous, contain porous angular basalt pebbles and fine-grained subrounded basalt pebbles.
AD 04	Substrate rock of crust	1,959	1,842	Basalt	Aphyric, porous, calcite fills vesicles.
AD 04	Rock	1,959	1,842	Basalt	Aphyric, porous, fragile by weathering.
AD 04	Rock	1,959	1,842	Basalt	Porous, some phenocrysts observed, discolored by weathering.
AD 04	Rock	1,959	1,842	Calcareous conglomerate	Contain angular basalt granules.
AD 12	Substrate rock of crust	1,968	2,024	Basalt	Aphyric, porous.
AD 08	Substrate rock of crust	2,045	1,877	Limestone	Abundant biological fragments, small basalt fragments mixed.
AD 16	Substrate rock of crust	2,253	2,039	Basalt	Phyric, vitreous, many cracks filled by calcite.
AD 16	Substrate rock of Cobble crust	2,253	2,039	Basalt	Phyric, porous, olivine observed.
AD 16	Substrate rock of Cobble crust	2,253	2,039	Calcareous conglomerate	Contain angular basalt pebbles, rock fragments, crust fragments. Matrix phosphatized.
AD 16	Rock	2,253	2,039	Calcareous conglomerate	Contain angular basalt pebbles, rock fragments, crust fragments. Matrix phosphatized.
LC 01	Substrate rock of Nodule	4,528		Phosphorite	Hard.
LC 01	Substrate rock of Nodule	4,528		Basalt	Small fragments.

Appendix Table 2 (4) Rock Samples from MS13 Area

Sample number	Rock type	Water depth (m)		Substrate	Description
		On bottom	Off bottom		
98 AD 09	Substrate rock of crust	1,822	1,801	Limestone	Pelitic, fragile, contain micronodules, some what phosphatized.
AD 09	Substrate rock of Cobble crust	1,822	1,801	Basalt	Fine grained, porous, acicular plagioclase crystals, vesicles filled by opal.
AD 09	Substrate rock of Nodule	1,822	1,801	Basalt	Fine grained, porous, acicular plagioclase crystals.
AD 09	Substrate rock of Nodule	1,822	1,801	Phosphorite	White, hard.
AD 09	Rock	1,822	1,801	Limestone	Pelitic, fragile, contain micronodules, some what phosphatized.
AD 02	Substrate rock of crust	1,897	1,784	Basalt	Fine grained, compact, acicular plagioclase notable.
AD 02	Substrate rock of Nodule	1,897	1,784	Basalt	Aphyric, fine grained, hard.
AD 02	Rock	1,897	1,784	Tuff	Fine grained.
AD 02	Rock	1,897	1,784	Limestone	Pelitic, fragile.
AD 05	Substrate rock of crust	2,033	1,885	Calcareous conglomerate	Matrix pelitic, soft. Pebbles basalt, phosphorite, nodules.
AD 05	Substrate rock of crust	2,033	1,885	Calcareous conglomerate	Matrix pelitic, soft. Pebbles basalt, subangular limestone.
AD 05	Substrate rock of crust	2,033	1,885	Calcareous conglomerate	Contain angular basalt pebbles. Matrix phosphatized, hard.
AD 05	Substrate rock of crust	2,033	1,885	Basalt	Fine grained, compact. Phyric but phenocrysts not clear.
AD 05	Substrate rock of Nodule	2,033	1,885	Basalt	Fine grained, compact. Phyric but phenocrysts not clear.
AD 05	Substrate rock of Nodule	2,033	1,885	Phosphorite	
AD 05	Rock	2,033	1,885	Calcareous conglomerate	Matrix pelitic, soft. Basalt granules.
AD 05	Rock	2,033	1,885	Basalt	Fine grained, compact. Phyric but phenocrysts not clear.
AD 08	Substrate rock of Cobble crust	2,039	1,912	Basalt	Fine grained, hard, aphyric.
AD 06	Substrate rock of crust	2,274	2,067	Basalt	Phyric, porous, phenocrysts not clear.
AD 06	Substrate rock of Nodule	2,274	2,067	Basalt	Phyric, porous, phenocrysts not clear.
AD 06	Rock	2,274	2,067	Basalt	Phyric, porous, phenocrysts not clear.
AD 10	Substrate rock of Nodule	2,318	2,196	Basalt	Fine grained, aphyric.
AD 10	Substrate rock of Nodule	2,318	2,196	Phosphorite	White, hard, contain micronodules.
AD 13	Substrate rock of crust	2,449	2,424	Basalt	Fine grained, aphyric, vesicles partly filled with calcite.
AD 13	Substrate rock of crust	2,449	2,424	Limestone	White, pelitic, fragile.
AD 13	Rock	2,449	2,424	Basalt	Fine grained, porous, aphyric.
AD 07	Substrate rock of Cobble crust	2,454	2,105	Calcareous conglomerate	Contain weathered basalt granules. Matrix phosphatized.
AD 07	Substrate rock of Cobble crust	2,454	2,105	Basalt	Cracks developed and filled by phosphate minerals.
AD 07	Substrate rock of Cobble crust	2,454	2,105	Phosphorite	White, hard.
AD 07	Substrate rock of Nodule	2,454	2,105	Basalt	
AD 07	Substrate rock of Nodule	2,454	2,105	Phosphorite	
AD 03	Substrate rock of crust	2,512	2,185	Basalt	Fine grained, aphyric, porous.
AD 03	Substrate rock of crust	2,512	2,185	Basalt	Fine grained, porous, rarely acicular plagioclase.
AD 03	Substrate rock of Cobble crust	2,512	2,185	Basalt	Fine grained, porous, rarely acicular plagioclase.
AD 03	Substrate rock of Nodule	2,512	2,185	Basalt	Fine grained, aphyric, porous.
AD 14	Substrate rock of crust	2,731	2,770	Basalt	Fine grained, hard, aphyric.
AD 14	Rock	2,731	2,770	Basalt	Fine grained, hard, aphyric.
AD 14	Rock	2,731	2,770	Limestone	Pelitic fragile. Pipe trace fossils on surface.
AD 04	Rock	2,886	2,318	Basalt	Fine grained, compact, acicular plagioclase notable.
AD 04	Rock	2,886	2,318	Tuff breccia	Fine grained, compact. Argillized by weathering.
AD 04	Rock	2,886	2,318	Limestone	Pelitic fragile, contain micronodules.
AD 15	Substrate rock of crust	3,120	2,910	Limestone	Pelitic, but coarse-grained material mixed. Brown by weathering.
LC 01	Substrate rock of Nodule	4,017		Basalt	Aphyric, porous.
LC 01	Substrate rock of Nodule	4,017		Tuff	Fine grained, compact.

Appendix Table 3(1) Description of microscopic observation for rock thin section

Sample: SMS10AD03T01

Rock: Vitreous basalt

Description(unaided eyes): Brown, crushed, fragile. Acicular plagioclase. White veinlets developed throughout. Crushed milky white clay minerals observed.

Description (microscopic) :

Rock texture: Phyric, porous. Both phenocryst and matrix plagioclase have weak flow structure. Smectite fills vesicles, show spherulitic～amygdaloidal texture.

Phenocryst minerals description:

Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Prismatic	2.4×0.4mm	10～20%	Weakly altered, prismatic, twins observed.

Matrix description:Cryptocrystalline～vitreous.

Mineral	Shape	Grain diameter	Content	Description
Volcanic glass.	Irregular.		50～60%	Weakly devitrizied, generally vitreous.

Alteration: Intermediate alteration. Volcanic glass partly altered (weak alteration) to clay minerals such as smectite.

Altered mineral description:

Mineral	Shape	Grain diameter	Content	Description
Smectite	Irregular.	0.01mm	Minor	Minor amount in volcanic glass. Partly veins.
	Splintery～Bounded	～0.1mm	10～20%	Splintery～bundled aggregate, fill vesicles.
	Irregular, Granular veins	～0.03mm	Minor	Minor amount in volcanic glass. Partly veins.

Sample: SMS10AD05T01

Rock: Altered basalt.

Description(unaided eyes): Reddish brown, autobrecciated. White clayey (or quartz?) veinlets in network.

Description (microscopic) :

Rock texture: Phyric, texture. Plagioclase phenocrysts with flow structure.

Phenocryst minerals description:

Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Prismatic Subhedral	0.3×1.8mm	20～25%	Relatively fresh
Olivine	Sort prismatic Subhedral	0.3×0.7mm	10%	Pseudomorph
Clinopyroxene		0.3×0.6mm	10%	Pseudomorph

Matrix description: Volcanic glass partly devitrified, altered to smectite. Silica minerals partly observed in matrix.

Mineral	Shape	Grain diameter	Content	Description
Smectite	Splintery	～0.1mm	60～70%	
Silica minerals	Spherulitic～Vein	～0.02mm	～5%	In matrix

Alteration: Strong alteration. Vitreous matrix partly devitrified, altered to smectite, weakly silicified.

Altered mineral description:

Mineral	Shape	Grain diameter	Content	Description
Smectite	Splintery	0.01mm	60～70%	Same as matrix.
Silica minerals	Spherulitic～vein	～0.02mm	5%	Same as matrix.

Appendix Table 3(2) Description of microscopic observation for rock thin section

Sample: SMS10AD08T03				
Rock: olivinee basalt.				
Description(unaided eyes): Brown, white veinlets developed. Prismatic euhedral crystal fragments on sample surface. Black, white spherulitic texture developed.				
Description (microscopic) :				
Rock texture: Spherulitic, micro-phyric texture developed.				
Phenocryst minerals description:				
Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Prismatic subhedral	0.3×0.4mm	~5%	Altered to quartz, smectite.
Matrix description:Clinopyroxene, opaque minerals, vitreous matrix.				
Mineral	Shape	Grain diameter	Content	Description
Clinopyroxene	Irregular. Prismtic	0.08~0.02mm	~60%	
Opaque mineral	Anhedral. Granular.	~0.05mm	~10%	Scattered in matrix
Volcanic glass	Irregular	~0.03mm	Minor	Weakly devitrified, smectite formed.
Alteration: Alteration intermediate. Smectitzed (vitreous matrix), iddingsitized (replacing olivinee). Smectite veins developed.				
Altered mineral description:				
Mineral	Shape	Grain diameter	Content	Description
Smectite	Pseudomorph replacement. Feathery.	~0.02mm	~5%	Volcanic glass, plagioclase replacement.
Iddingsite	Pseudomorph replacement. Vein.	~0.02mm	~5%	Olvine replacement.

Sample: SMS11AD06T01				
Rock: Porphyritic spherulitic olivinee basalt.				
Description(unaided eyes): Brown, compact clayey. Consist of white prismatic plagioclase phenocrysts.				
Description (microscopic) :				
Rock texture: Phyric, vitreous matrix. Phenocryst・matrix plagioclase show weak flow structure. Smectite and calcite fill voids with spherulitic~amygdaloidal texture.				
Phenocryst minerals description:				
Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Euhedral~Subhedral	0.9×1.3mm	~10%	Pseudomorph by alteration (smectitization)
Olivine	Euhedral~Subhedral	0.9×1.3mm	~10%	Some fresh olivinee, but mostly pseudomorph (smectite, iddingsite).
Matrix description: Vitreous matrix consisting of plagioclase and opaque minerals.				
Mineral	Shape	Grain diameter	Content	Description
Volcanic glass	Irregular		20~30%	
Opaque minerals	Fibrous	0.05~0.1mm	5~10%	Scattered in matrix.
Alteration: Alteration medium. Phenocrysts mostly altered to clay minerals such as smectite.				
Altered mineral description:				
Mineral	Shape	Grain diameter	Content	Description
Smectite	Pseudomorph, splintery,Ggranular	~1mm	~10%	Pseudomorph replacement with plagioclase and olivinee. Fill voids.
Calcite	Splintery, pseudomorph, Granular	~1mm	~1%	Fill voids.
Iddingsite		~0.02mm	Minor	Pseudomorph replacement with olivinee.

Appendix Table 3(3) Description of microscopic observation for rock thin section

Sample: SMS11AD09T01

Rock: Microphyric spherulitic olivinee basalt.

Description(unaided eyes): Greenish brown, compact. Blackish brown spherulitic texture observed. White incrustation on surface.

Description (microscopic) :

Rock texture: Vitreous, Microphyric. Smectite fills voids with spherulitic～amygdaloidal texture.

Phenocryst minerals description:

Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Prismatic subhedral	0.4×2.0mm	10～15%	Fresh
Olivine	Sort prismatic subhedral	0.6×1.0mm	～5%	Altered, pseudomorph (iddingsitized)

Matrix description:Vitreous, consisting of plagioclase, opaque minerals.

Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Acicular, subhedral	0.01×0.2mm	15～20%	Relatively fresh
Opaque minerals	Microgranular	～10%	～5%	Scattered in matrix.
Volcanic glass	Irregular	～40%		

Alteration: Alteration weak. olivinee phenocrysts altered pseudomorph. Matrix devitrification weak.

Altered mineral description:

Mineral	Shape	Grain diameter	Content	Description
Smectite	Radial, spherulitic, splintery, Microgranular.	～0.5mm	5～10%	Void filling, center hallow.
Iddingsite		～0.2mm	Rare	Pseudomorph of olivinee, alteration mineral.
Silica minerals		～0.01mm	Rare	Partly veins.

Sample: SMS12AD04T03

Rock: Microphyric spherulitic olivinee basalt.

Description(unaided eyes): Reddish brown, porous (vesiculation?), reddish yellow brown incrustation on surface, Coarse-grained (max 7mm) phenocrysts (plagioclase) observed.

Description (microscopic) :

Rock texture: Phyric, Vitreous matrix, porous. Voids filled by smectite with spherulitic～amygdaloidal texture. Phenocrysts・matrix plagioclase show clear flow structure.

Phenocript minerals description:

Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Subhedral, prismatic.	Max: 2.4×0.4mm	～20%	Megaphenocryst, twins, weak zonal structure.
olivine	Subhedral, sort prismatic.	Max: 1.0×0.6mm	～10%	Pseudomorph (smectite)
Clinopyroxene	Subhedral, sort prismatic.	Max: 0.8×0.6mm	～10%	Pseudomorph (smectite)

Matrix description: Vitreous matrix, vermicular plagioclase developed. Spherulitic～porous structure developed in matrix. Opaque minerals observed.

Mineral	Shape	Grain diameter	Content	Description
Volcanic glass	Void filling		～10%	Weakly devitrified.
Plagioclase	Prismatic～acicular.	0.1×0.02mm	～40%	Clear flow structure.
Opaque minerals	Anhedral, microgranular.	0.005～0.1mm	～10%	Scattered in matrix.

Alteration: Generally weakly altered except mafic minerals. Dvitrification also weak.

Altered mineral description:

Mineral	Shape	Grain diameter	Content	Description
Smectite	Splintery, bundle.	0.01～0.05mm		Formed as alteration mineral of olivine and pyroxene. Also developed filling voids.

Appendix Table 3(4) Description of microscopic observation for rock thin section

Sample: SMS12AD07T01				
Rock: Basaltic pyroclastic rocks.				
Description(unaided eyes): Coarse angular~subangular pebbles. 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.				
Description (microscopic) :				
Rock texture: Clastic pebble texture.				
Pebbles description: All phenocrysts altered, smectitized (pisolitic, oolitic, spherulitic). Strongly weathered pebbles, matrix also smectitized. Volcanic glass partly remain in weakly weathered pebbles.				
Mineral	Shape	Grain diameter	Content	Description
Volcanic glass	Irregular		~5%	Only in weak weathered pebbles.
Matrix description: Vitreous~sandy matrix, aphyric. Smectite, silica minerals, chlorite. Quartz and apatite veins developed (the ratio below is for matrix).				
Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Subhedral, Prismatic.	0.01~0.05mm	~5%	Partly weathered.
Volcanic glass	Irregular		~25%	
Alteration: Pebbles are altered with very strong devitrification, there are no phenocrysts. Pisolitic, oolitic~spherulitic smectite formed. Degree of alteration diverse by pebbles. In matrix smectite, silica minerals, chlorite alteration observed.				
Altered mineral description: The description is for matrix.				
Mineral	Shape	Grain diameter	Content	Description
Smectite	(Pebble) pisolitic, spherulitic etc.	0.2~0.5mm	~20%	Pisolitic, spherulitic smectite covered by colloform smectite of similar nature.
	(Matrix) colloform	~0.1mm	~45%	Altered from volcanic glass.
Silica minerals	Fine granular	~0.05mm	Minor	Formed in matrix, partly amorphous, spherulitic~amygdaloidal.
Chlorite	Vein	~0.1mm	Minor	Veins developed in matrix.

Sample: SMS12AD16T01				
Rock: Basaltic pyroclastic rocks・globigerina carbonatie psammitic mudstone.				
Description(unaided eyes): Consist of subangular pebbles of basaltic pyroclastic rocks. Pebble are diverse such as basaltic pebbles and globigerina carbonatic psammitic mudstone pebbles. Alteration degree diverse for basalt pebbles. Matrix glassy~sandy.				
Description (microscopic) :				
Rock texture: Clastic pebble texture.				
Pebble description: Basalt pebbles strongly altered, aphyric. Matrix mostly smectitized. Plagioclase remain in weakly altered pebble. Globigerina mudstone also contains microfossils such as radiolarian.				
Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Prismatic subhedral	~0.05mm	~5%	Only in matrix of weakly altered pebbles.
Calcite	Microfossil		~30%	In psammitic mudstone pebbles.
Matrix description: Glassy~sandy. Alteration weaker than basaltic pebbles. Volcanic glass remain.				
Mineral	Shape	Grain diameter	Content	Description
Volcanic glass	Irregular		~30%	Partly altered to smectite and silica minerals.
Alteration: Alteration strong for pebbles, smectite developed. Alteration week for matrix, volcanic glass remain.				
Altered mineral description:				
Mineral	Shape	Grain diameter	Content	Description
Smectite	Cryptocrystalline	~0.01mm	~30%	Observed in pebbles nd matrix.
Silica minerals.	Anhedral		~5%	Observed in matrix.

Appendix Table 3(5) Description of microscopic observation for rock thin section

Sample: SMS13AD02T02				
Rock: Hyaloclastite				
Description(unaided eyes): Brown hyaloclastite. Do not contain pebbles. Coarse grained～pisolitic. Voids (milky white incrustation inside) observed locally.				
Description (microscopic) :				
Rock texture: Clastic, network veins developed. Pockets of calcite.				
Clasts description: Consist of clay minerals and opaque minerals.				
Mineral	**Shape**	**Grain diameter**	**Content**	**Description**
Clay minerals	Colloform	～0.05mm	20～30%	Formed as clast grains or cementing matter.
Opaque minerals.	Fine granular	～0.02mm	～20%	Developed as clast grains.
Matrix description: Very minor amount of microfossil fragments (species unknown) observed.				
Mineral	**Shape**	**Grain diameter**	**Content**	**Description**
Calcite	Spheroidal	～0.1mm	Rare	Pocket-form aggregates, developed as secondary veinlets.
Volcanic glass	Irregular		～20%	
Alteration: Alteration intermediate. In matrix, smectite and silica minerals formed as cementing matter (colloform, void filling). Believed to be diagenetic product. These occur also in veinlets.				
Altered mineral description:				
Mineral	**Shape**	**Grain diameter**	**Content**	**Description**
Smectite	colloform	0.01～0.05mm	～20%	Alteration product of calcite grains or cementing matter. Veinlets also developed.
Silica minerals.	Anhedral fine granular aggregate.	～0.01mm	～5%	Formed together with smectite. Veinlets also developed.
	Fine granule, anhedral.	～0.01mm	5～10%	Developed filling clastic grain interstices

Sample: SMS13AD03T01				
Rock: Aphyric porous basalt. Altered basalt.				
Description(unaided eyes): Brown, compact, porous (brick-like appearance). Grayish white filling observed locally.				
Description (microscopic) :				
Rock texture: Aphyric porous. Matrix Phyric, texture. Plagioclase show weak flow structure. Vitreous～cryptocrystalline. Voids filled by smectite showing spherulitic～amygdaloidal structure.				
Phenocript minerals description: Basically aphyric.				
Mineral	**Shape**	**Grain diameter**	**Content**	**Description**
Plagioclase	Subhedral, granular	0.1×0.2mm	～2%	Very minor amount (fell out?)
Clinopyroxene	Subhedral, granular	0.8×0.2mm	～2%	Pseudomorph, clay minerals.
Matrix description: Generally vitreous～cryptocrystalline.				
Mineral	**Shape**	**Grain diameter**	**Content**	**Description**
Plagioclase	Acicular～prismatic	0.02×0.4mm	～40%	Rapid growth (quenched product?)
Silica minerals	Cryptocrystalline	～0.01mm	～10%	Small amount in matrix.
Opaque minerals			～10%	
Volcanic glass	Irregular		～30%	
Alteration: In phenocrysts, clinopyroxene is argillized (smectite), alteration significant. Matrix partly argillized (smectite), but alteration generally weak.				
Altered mineral description:				
Mineral	**Shape**	**Grain diameter**	**Content**	**Description**
Smectite	Splintery～flat.	0.01～0.05mm	～5%	Replaced pyroxene phenocryst pseudomorphically. Also fill voids in matrix in pools and patches.
	Ggranular.	0.4～0.6mm	～5%	

Appendix Table 4 Results of FDC survey in MS Area

Area	Track Line No.	Item	Date&Time (UTC)	FDC Position Latitude(N)	FDC Position Longitude(E)	Depth (m)	General Location	Observation Time	Observation Length	No. of Photos	8mm VTR
MS10	98SMS10FDC01	IS	May 12 20:56					2:50	2.5	150	2
		SP	May 12 21:32	12° 23.160´N	158° 39.471´E	1,396	north edge part of the summit				
		EP	May 13 00:22	12° 24.553´N	158° 41.529´E	2,816	middle part of northeast flank				
		OD	May 13 01:27								
MS11	98SMS11FDC01	IS	May 18 20:55					2:56	3.2	142	2
		SP	May 18 21:34	10° 57.339´N	161° 30.822´E	1,611	east edge part of the summit				
		EP	May 19 00:30	10° 57.276´N	161° 34.053´E	2,919	lower part of east flank				
		OD	May 19 01:29								
MS12	98SMS12FDC01	IS	May 25 20:58					1:40	2.2	82	1
		SP	May 25 21:28	8° 43.282´N	163° 09.470´E	1,066	summit of south part of seamount				
		EP	May 25 23:08	8° 42.719´N	163° 11.598´E	1,385	upper part of southeast flank				
		OD	May 25 23:43								
	98SMS12FDC02	IS	May 26 00:12					2:18	2.4	90	2
		SP	May 26 00:45	8° 43.583´N	163° 15.502´E	1,300	east edge part of the summit				
		EP	May 26 03:03	8° 43.620´N	163° 17.944´E	2,564	middle part of east flank				
		OD	May 26 03:54								
MS13	98SMS13FDC01	IS	Jun 04 20:56					2:20	2.2	102	2
		SP	Jun 04 21:38	8° 10.447´N	160° 34.849´E	1,458	north edge part of the summit				
		EP	Jun 04 23:58	8° 09.310´N	160° 36.782´E	2,707	lower part of northeast flank				
		OD	Jun 05 00:52								
	98SMS13FDC02	IS	Jun 05 02:47					2:01	1.7	90	2
		SP	Jun 05 03:39	8° 27.502´N	160° 37.472´E	2,633	summit of south part of seamount				
		EP	Jun 05 05:40	8° 28.423´N	160° 38.932´E	3,287	middle part of southeast flank				
		OD	Jun 05 06:45								

Legend IS:FDC into the sea, SP:Start point of observation, EP:End point of observation, and OD:FDC on the deck
Note FDC position is calculated by GPS ship position, CTD depth of FDC and wire length.

Appendix Table 5 (1) Results of chemical analysis of cobalt-rich crust

sample	sampling depth(m)	code	type of crust	thickness (mm) aver	thickness (mm) max	thickness (mm) min	substrate	condition of surface	analysed part	Co	Ni	Cu	Mn	Fe	Pb	Zn	Ti	Mo	V	Si	Al	Ca	P	Pt	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Mn/Fe
										%	%	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	
MS10-area																																							
98SMS10LC01CM01	5516	A	nodule	10	17	7	crust, phospholite	mooth/granule	bulk	0.332	0.405	0.229	18.12	16.70	0.07	0.06	1.13	0.033	0.040	8.98	3.58	1.87	0.33	0.126	129	824	38.9	156	34	8.77	31	5.8	35	6.9	21	3.02	19	3.27	1.09
98SMS10AD02CM01	1599	A	fragment	28	28	28		botryoidal	bulk	1.028	0.651	0.023	24.64	14.36	0.14	0.07	0.79	0.061	0.056	2.81	0.58	2.25	0.27	0.298	162	757	36.5	151	31	8.01	31	5.7	36	7.8	25	3.95	24	4.19	1.72
98SMS10AD03CM04	1770	E	fragment	24	24	24		botryoidal	bulk	0.452	0.338	0.067	18.28	16.08	0.10	0.06	0.86	0.035	0.043	3.68	1.12	2.61	0.41	0.576	136	633	28.9	121	23	6.17	24	4.3	26	5.8	18	2.68	17	2.96	1.14
98SMS10AD04CM02	2023	A1	crust	-	-	-	tuff	botryoidal	surface	0.669	0.388	0.002	22.03	16.31	0.13	0.05	0.85	0.046	0.049	4.11	0.78	1.96	0.32	0.148	185	698	40.5	177	36	9.26	37	6.7	41	8.5	27	4.17	25	4.14	1.35
98SMS10AD04CM03	2023	A2	crust	-	-	-	tuff	granule	side	0.897	0.404	<0.001	21.89	16.77	0.13	0.06	1.16	0.042	0.049	5.14	1.23	2.70	0.24	0.283	189	932	42.7	180	38	9.62	36	7.1	43	8.8	27	4.28	26	4.45	1.31
98SMS10AD05CM01	1445	A	fragment	18	24	7		botryoidal	bulk	0.882	0.484	0.002	22.23	13.48	0.15	0.06	0.91	0.045	0.047	1.33	0.33	1.97	0.24	1.207	170	945	37.4	157	31	7.63	26	5.4	32	7.0	21	3.27	19	3.30	1.65
98SMS10AD06CM01	2094	A	fragment	20	20	20		granule	bulk	1.111	0.459	<0.001	22.99	16.23	0.14	0.06	1.29	0.033	0.045	2.62	0.57	2.39	0.29	0.639	208	1211	45.3	191	40	10.00	34	7.2	44	8.9	27	4.26	27	4.29	1.42
98SMS10AD07CM02	1728	B	fragment	25	25	25		granule	bulk	0.777	0.449	0.051	21.10	14.20	0.13	0.06	1.02	0.034	0.046	1.60	0.35	1.89	0.23	2.040	180	1018	39.1	160	32	7.83	28	5.5	33	6.8	21	3.14	20	3.26	1.49
98SMS10AD08CM01	1415	A	cobble	100	100	90	basalt	botryoidal	bulk	0.561	0.419	0.019	20.00	14.45	0.11	0.06	0.76	0.050	0.045	2.26	0.64	4.01	1.13	0.362	155	701	33.7	142	29	7.50	28	5.4	32	6.8	21	3.28	20	3.42	1.38
98SMS10AD08CM02	1415	A1	cobble	20	22	19	-	-	outer	1.024	0.546	<0.001	24.15	14.77	0.16	0.06	0.79	0.060	0.053	3.01	0.44	2.09	0.35	0.281	157	758	36.3	151	31	7.94	30	5.7	34	7.5	23	3.55	22	3.80	1.63
98SMS10AD08CM03	1415	A2	cobble	30	30	30	-	-	inner	0.405	0.433	0.030	20.07	19.86	0.13	0.08	1.03	0.044	0.054	4.40	1.44	2.40	0.56	0.605	180	749	39.5	165	34	8.78	32	6.1	37	7.8	23	3.55	23	3.91	1.01
98SMS10AD08CM04	1415	A3	cobble	50	55	45	-	-	innermost	0.348	0.516	0.048	19.55	11.42	0.10	0.07	0.49	0.061	0.046	0.89	0.26	11.64	3.97	0.346	170	641	33.4	143	27	6.92	29	5.3	32	7.1	23	3.38	20	3.52	1.71
98SMS10AD08CM05	1415	B	cobble	40	60	20	basalt	botryoidal	bulk	0.444	0.463	0.034	17.61	10.83	0.11	0.06	0.52	0.046	0.039	1.04	0.31	11.06	3.72	0.608	172	736	32.8	138	27	6.92	26	5.1	33	7.6	23	3.58	22	3.92	1.63
98SMS10AD08CM06	1415	B1	cobble	10	15	5	-	-	outer	1.065	0.562	0.003	23.93	15.42	0.18	0.06	0.68	0.069	0.063	1.94	0.43	[illegible]	0.57	0.221	196	721	43.9	190	40	9.89	37	7.3	43	8.9	28	4.22	25	4.22	1.55
98SMS10AD08CM07	1415	B2	cobble	7	15	0	-	-	inner(1)	0.565	0.565	0.033	23.23	20.18	0.17	0.08	1.07	0.049	0.065	2.92	0.89	2.29	0.41	0.744	200	902	43.8	185	38	9.52	33	6.5	39	8.2	25	3.93	24	4.06	1.15
98SMS10AD08CM08	1415	B3	cobble	6	15	0	-	-	inner(2)	0.500	0.820	0.064	25.41	11.91	0.17	0.09	0.62	0.042	0.054	1.04	0.33	8.77	2.25	0.426	301	1035	52.1	234	45	11.70	51	8.6	57	13.0	41	6.19	37	5.90	2.13
98SMS10AD08CM09	1415	B4	cobble	27	30	25	-	-	innermost	0.261	0.324	0.034	15.00	9.14	0.09	0.06	0.43	0.040	0.039	0.81	0.30	17.74	5.25	0.600	197	951	37.7	169	31	8.00	29	5.8	37	8.2	27	4.15	25	4.34	1.64
98SMS10AD08CM15	1415	D	cobble	50	60	45	conglomerate	botryoidal	bulk	0.532	0.492	0.024	20.39	12.09	0.12	0.06	0.58	0.056	0.051	1.15	0.31	10.41	2.91	0.341	219	853	45.6	207	38	9.71	38	7.2	45	9.9	32	4.85	29	5.01	1.69
98SMS10AD08CM16	1415	D1	cobble	8	11	6	-	-	outer	0.956	0.562	<0.001	22.37	14.81	0.16	0.06	0.81	0.058	0.055	1.79	0.42	2.15	0.34	0.201	171	844	41.6	181	36	9.35	32	6.2	38	8.0	23	3.73	23	3.73	1.51
98SMS10AD08CM17	1415	D2	cobble	18	26	15	-	-	inner(1,2)	0.195	0.264	0.034	14.62	10.53	0.09	0.05	0.42	0.026	0.042	0.98	0.30	19.49	6.61	0.691	355	939	39.2	172	33	8.43	37	6.3	41	9.9	32	4.81	29	4.93	1.39
98SMS10AD08CM18	1415	D3	cobble	20	30	10	-	-	innermost	0.569	0.722	0.031	23.14	12.32	0.13	0.08	0.65	0.069	0.056	0.91	0.23	6.85	1.71	0.324	238	903	53.2	236	44	11.10	44	8.3	51	11.0	34	5.18	30	5.12	1.88
98SMS10AD08CM29	1415	G	cobble	50	60	40	limestone	botryoidal	bulk	0.529	0.557	0.041	21.79	14.14	0.13	0.07	0.70	0.053	0.053	1.57	0.51	8.46	2.21	0.665	194	831	38.8	170	32	8.63	32	6.0	40	9.4	29	4.40	28	5.02	1.54
98SMS10AD08CM30	1415	G1	cobble	9	11	8	-	-	outer	1.067	0.681	0.023	25.07	16.36	0.18	0.08	0.86	0.069	0.059	2.55	0.65	2.82	0.43	0.602	167	902	38.6	174	33	8.60	31	6.2	38	8.4	26	4.09	26	4.43	1.53
98SMS10AD08CM31	1415	G2	cobble	10	20	6	-	-	inner(1)	0.630	0.537	0.024	22.69	18.90	0.16	0.08	1.12	0.042	0.052	3.21	0.96	2.34	0.58	0.624	151	854	33.9	148	28	7.30	25	5.2	31	6.7	22	3.45	21	3.68	1.20
98SMS10AD08CM32	1415	G3	cobble	17	20	15	-	-	inner(2)	0.507	0.753	0.065	23.24	12.64	0.12	0.09	0.67	0.060	0.048	1.04	0.44	7.16	1.68	0.536	194	770	43.1	192	34	9.02	37	6.7	41	9.4	30	4.52	27	4.93	1.84
98SMS10AD08CM33	1415	G4	cobble	16	17	15	-	-	inner(3),innermost	0.215	0.365	0.045	16.01	11.10	0.10	0.06	0.43	0.039	0.045	0.98	0.34	16.08	4.27	0.756	358	869	40.5	185	33	8.65	38	7.0	45	11.0	36	5.46	33	6.11	1.44
98SMS10AD09CM01	2081	A	cobble	115	115	115	crust	smooth	bulk	0.511	0.460	0.048	20.86	15.87	0.13	0.07	0.74	0.054	0.056	1.84	0.43	5.00	1.17	0.323	220	926	53.2	230	45	11.70	42	8.0	48	9.9	30	4.54	27	4.50	1.31
98SMS10AD09CM02	2081	A1	cobble	18	18	8	-	-	outer	0.625	0.390	0.002	23.94	17.49	0.16	0.06	0.77	0.064	0.060	2.26	0.36	2.26	0.34	0.093	227	783	54.8	250	48	12.30	50	9.1	54	12.0	35	5.20	31	5.31	1.37
98SMS10AD09CM03	2081	A2	cobble	11	11	11	-	-	inner(1)	0.445	0.377	0.026	21.59	22.51	0.16	0.08	1.09	0.051	0.068	3.46	0.75	2.26	0.38	0.353	438	908	76.1	338	67	16.20	61	11.0	60	12.0	33	4.94	29	4.66	0.96
98SMS10AD09CM04	2081	A3	cobble	35	35	35	-	-	inner(2,3)	0.539	0.463	0.054	23.70	18.33	0.11	0.08	0.89	0.090	0.050	1.56	0.33	2.19	0.26	0.391	318	856	64.3	284	54	13.50	52	8.8	49	9.5	27	4.04	23	3.73	1.29
98SMS10AD09CM05	2081	A4	cobble	28	28	28	-	-	inner(4,5)	0.190	0.292	0.055	15.15	12.04	0.09	0.05	0.44	0.043	0.045	1.35	0.40	14.11	3.85	0.290	204	961	44.9	199	37	9.83	37	6.7	42	9.4	29	4.29	26	4.59	1.26
98SMS10AD09CM06	2081	A5	cobble	23	23	23	-	-	innermost	0.358	0.430	0.054	20.68	13.15	0.11	0.06	0.68	0.063	0.057	1.24	0.30	10.18	2.86	0.360	230	1561	57.6	238	45	11.50	36	7.5	46	9.9	30	4.39	28	4.76	1.57
98SMS10AD10CM02	2005	B	fragment	13	20	11		granule	bulk	1.111	0.497	0.011	25.48	16.39	0.14	0.06	1.28	0.038	0.054	2.49	0.47	2.79	0.38	0.816	341	1390	48.0	210	43	10.60	42	7.0	44	9.0	27	4.20	26	4.03	1.55
98SMS10AD12CM01	2097	A	fragment	43	45	40		botryoidal	bulk	0.710	0.515	0.048	21.96	14.27	0.11	0.06	0.82	0.044	0.046	2.66	0.60	2.17	0.32	0.475	152	670	35.4	159	33	8.24	31	6.0	38	7.8	24	3.75	24	4.10	1.54
98SMS10AD12CM02	2097	A1	fragment	23	24	22		-	outer	0.901	0.569	0.069	23.66	14.85	0.12	0.06	0.85	0.057	0.046	2.83	0.62	2.16	0.27	0.377	153	662	37.8	167	33	8.58	34	6.3	39	8.6	27	4.22	26	4.53	1.59
98SMS10AD12CM03	2097	A2	fragment	22	24	22		-	inner	0.730	0.619	0.079	23.50	18.14	0.13	0.07	1.26	0.044	0.052	2.93	0.79	2.47	0.31	1.054	200	901	45.5	209	42	10.80	40	7.7	48	9.9	30	4.83	30	4.91	1.30
98SMS10AD15CM01	1409	A	fragment	40	50	-		botryoidal	bulk	0.630	0.444	0.030	19.68	12.77	0.11	0.06	0.72	0.041	0.044	1.09	0.29	6.92	1.77	0.855	170	787	36.6	170	32	7.92	31	6.0	38	8.5	28	4.18	25	4.55	1.54
98SMS10AD15CM02	1409	A1	fragment	8	10	7		botryoidal	outer	1.332	0.549	<0.001	23.82	15.42	0.16	0.06	0.92	0.059	0.055	1.75	0.39	2.39	0.36	0.326	172	866	41.9	190	38	9.72	35	7.2	43	8.8	27	4.29	25	4.28	1.55
98SMS10AD15CM03	1409	A2	fragment	9	12	7		botryoidal	inner(1)	0.787	0.559	0.026	23.22	16.91	0.15	0.08	1.10	0.045	0.058	1.75	0.43	2.39	0.28	0.691	169	950	43.4	184	36	9.09	33	5.9	36	7.6	23	3.48	21	3.38	1.37
98SMS10AD15CM04	1409	A3	fragment	17	19	14		botryoidal	inner(2)	0.464	0.638	0.055	23.17	12.79	0.13	0.08	0.64	0.059	0.052	0.98	0.32	6.99	1.86	0.440	207	982	43.1	202	40	10.30	37	7.8	50	11.0	35	5.43	33	5.49	1.81
98SMS10AD15CM05	1409	A4	fragment	18	26	11		botryoidal	inner(3),innermost	0.219	0.277	0.041	13.65	10.48	0.09	0.05	0.38	0.036	0.041	0.79	0.24	17.13	5.61	0.732	213	779	37.9	176	32	8.44	34	6.8	47	11.0	35	5.70	34	6.11	1.32

Appendix Table 5 (2) Results of chemical analysis of cobalt-rich crust

sample	sampling depth(m)	code	type of crust	thickness (mm) aver	max	min	substrate	condition of surface	analyzed part	Co %	Ni %	Cu %	Mn %	Fe %	Pb %	Zn %	Ti %	Mo %	V %	Si %	Al %	Ca %	P %	Pt ppm	La ppm	Ce ppm	Pr ppm	Nd ppm	Sm ppm	Eu ppm	Gd ppm	Tb ppm	Dy ppm	Ho ppm	Er ppm	Tm ppm	Yb ppm	Lu ppm	Mn/Fe
MS11-area																																							
98SMS11CB02CM07	2034	B	cobble	70	95	40	basalt	botryoidal	bulk	0.587	0.520	0.054	22.67	16.11	0.10	0.08	0.85	0.084	0.060	1.81	0.44	3.44	0.79	0.323	176	733	43.4	195	39	9.88	35	6.9	42	8.6	26	4.09	25	4.18	1.41
98SMS11CB02CM08	2034	B1	-	10	15	3	-	-	outer(1)	1.143	0.760	0.027	25.58	14.14	0.13	0.08	0.89	0.065	0.056	2.07	0.48	2.56	0.36	0.186	153	655	39.6	176	35	9.17	35	6.5	41	8.8	26	4.07	25	4.36	1.81
98SMS11CB02CM09	2034	B2	-	3	13	0	-	-	outer(2)	0.659	0.539	0.062	22.19	18.63	0.11	0.09	1.03	0.062	0.065	2.24	0.55	2.27	0.34	0.420	186	760	47.4	209	40	10.10	38	7.1	41	8.6	27	3.96	24	4.22	1.19
98SMS11CB02CM10	2034	B3	-	5	9	3	-	-	inner(1)	0.657	0.607	0.072	23.41	18.01	0.12	0.10	0.94	0.065	0.076	1.95	0.51	2.99	0.42	0.450	191	786	47.9	216	41	10.30	39	7.4	44	9.1	28	4.28	25	4.45	1.30
98SMS11CB02CM11	2034	B4	-	4	8	0	-	-	inner(2)	0.434	0.730	0.086	23.48	12.43	0.11	0.09	0.67	0.066	0.057	1.28	0.37	9.38	2.66	0.354	208	1031	46.5	218	41	10.80	43	8.5	54	13.0	41	6.35	39	6.87	1.89
98SMS11CB02CM12	2034	B5	-	7	11	5	-	-	inner(3)	0.273	0.469	0.058	20.26	12.28	0.09	0.07	0.55	0.052	0.044	1.35	0.38	11.74	3.64	0.377	173	947	35.8	165	31	8.01	29	6.1	40	9.1	29	4.58	28	4.93	1.65
98SMS11CB02CM13	2034	B6	-	4	5	3	-	-	inner(4)	0.172	0.277	0.055	15.20	12.56	0.09	0.05	0.41	0.037	0.043	1.35	0.38	15.32	5.14	0.424	204	801	43.4	193	35	9.23	35	6.6	43	10.0	32	4.71	30	5.44	1.21
98SMS11CB02CM14	2034	B7	-	18	27	10	-	-	inner(5)	0.370	0.437	0.062	20.48	12.00	0.12	0.08	0.65	0.048	0.053	1.32	0.41	12.99	3.20	0.510	236	1297	53.8	230	42	11.30	40	8.1	52	12.0	39	5.68	38	7.00	1.71
98SMS11CB02CM26	2034	F	fragment	30	35	25		botryoidal	bulk	0.905	0.553	0.046	24.14	13.04	0.11	0.08	1.09	0.044	0.046	1.31	0.30	2.31	0.28	0.338	161	1256	41.2	175	35	8.65	30	6.0	37	7.4	23	3.57	22	3.56	1.85
98SMS11CB03CM01	2381	A	fragment	17	20	15		granule	bulk	1.031	0.584	0.062	22.29	13.63	0.12	0.07	0.99	0.054	0.050	1.95	0.47	2.36	0.21	1.489	155	841	40.8	177	36	8.82	29	6.5	38	7.5	23	3.75	22	3.68	1.63
98SMS11CB05CM01	2374	A	crust	12	15	9	limestone	botryoidal	bulk	0.632	0.369	0.026	20.56	17.47	0.11	0.05	0.89	0.038	0.054	5.14	1.13	2.77	0.28	0.174	166	773	43.6	198	39	9.74	38	7.4	44	8.9	28	4.36	25	4.32	1.18
98SMS11CB07CM01	2077	A	fragment	40	50	35		botryoidal	bulk	0.460	0.444	0.073	20.12	13.58	0.11	0.07	0.74	0.035	0.063	1.53	0.46	6.61	1.20	0.680	199	1181	44.6	193	37	8.98	30	6.7	42	8.9	29	4.49	26	4.59	1.48
98SMS11CB08CM01	1952	B	fragment	60	90	35		botryoidal	bulk	0.629	0.412	0.037	20.19	13.85	0.12	0.06	0.82	0.030	0.051	1.50	0.39	6.08	1.07	0.864	181	1036	40.4	175	33	8.43	31	5.9	39	8.8	28	4.33	27	4.54	1.46
98SMS11CB08CM02	1952	B1	-	15	20	5	-	-	outer	1.140	0.543	0.001	24.15	17.14	0.16	0.07	1.00	0.060	0.066	2.66	0.57	2.46	0.29	0.171	192	957	49.0	213	43	11.00	44	7.6	48	10.0	32	4.71	29	4.88	1.41
98SMS11CB08CM03	1952	B2	-	18	20	15	-	-	inner(1)	0.879	0.452	0.016	22.29	19.39	0.13	0.07	1.42	0.038	0.055	4.20	1.28	2.85	0.43	0.497	164	1069	39.6	168	32	8.27	29	5.6	36	7.8	25	3.82	24	4.15	1.15
98SMS11CB08CM04	1952	B3	-	7	10	5	-	-	inner(2)	0.792	0.505	0.046	24.16	17.81	0.14	0.09	1.23	0.063	0.071	2.07	0.53	2.46	0.27	0.447	187	1159	46.5	197	40	9.31	30	6.1	39	7.7	23	3.78	23	3.73	1.36
98SMS11CB08CM05	1952	B4	-	1	15	10	-	-	inner(3)	0.566	0.465	0.063	24.08	21.67	0.12	0.10	0.94	0.081	0.079	1.96	0.55	2.38	0.40	0.425	194	876	50.9	208	40	9.96	38	6.3	39	7.8	23	3.50	22	3.60	1.11
98SMS11CB08CM06	1952	B5	-	12	15	10	-	-	inner(4)	0.470	0.620	0.061	24.53	13.10	0.13	0.08	0.70	0.051	0.059	1.20	0.34	8.74	2.41	0.438	229	1160	48.7	225	41	10.40	45	8.0	52	12.0	39	5.86	34	5.93	1.87
98SMS11CB08CM07	1952	B6	-	16	18	15	-	-	inner(5)	0.166	0.244	0.036	14.84	13.45	0.10	0.05	0.46	0.026	0.051	1.38	0.38	16.76	5.41	0.387	161	1002	35.0	151	29	7.21	25	5.0	31	6.7	21	3.20	20	3.31	1.10
98SMS11CB09CM01	2515	A	crust	100	140	40	basalt	botryoidal	bulk	0.513	0.336	0.051	20.56	15.08	0.17	0.06	1.19	0.037	0.060	1.66	0.43	8.81	2.40	0.807	304	1741	71.2	298	52	12.20	46	8.7	52	11.0	36	5.26	31	5.31	1.36
98SMS11CB10CM01	2667	A	nodule	4.5	4.5	4.5	phosphorite	granule	bulk	0.765	0.625	0.056	23.28	16.48	0.12	0.06	1.03	0.054	0.057	3.08	0.80	2.74	0.46	0.227	179	892	50.0	214	41	10.20	43	7.1	44	8.9	26	4.21	26	4.44	1.41
MS12-area																																							
98SMS12LC01CM01	4528	A	nodule	12	13	12	phosphorite	smooth	bulk	0.399	0.374	0.161	21.23	17.82	0.09	0.06	1.09	0.030	0.055	5.10	1.52	2.19	0.24	0.125	195	1108	61.9	276	58	13.60	52	9.3	54	10.0	31	4.59	26	4.19	1.19
98SMS12AD02CM04	1554	D	crust	40	42	30	conglomerate	botryoidal	bulk	0.932	0.547	<0.001	24.71	15.28	0.16	0.07	0.95	0.075	0.070	1.59	0.32	2.81	0.32	0.189	193	983	50.1	219	42	10.40	42	7.3	44	9.3	30	4.53	26	4.28	1.62
98SMS12AD02CM05	1554	D1	-	7	10	4	-	-	outer	1.071	0.540	<0.001	26.90	17.08	0.18	0.07	0.86	0.094	0.075	1.94	0.39	2.67	0.41	0.159	183	902	41.8	193	39	9.68	40	7.3	48	11.0	34	5.37	31	5.40	1.58
98SMS12AD02CM06	1554	D2	-	11	20	7	-	-	inner	0.787	0.503	0.016	25.30	18.01	0.19	0.08	1.23	0.061	0.071	2.31	0.46	2.52	0.41	0.175	199	1145	48.3	217	42	10.70	39	7.5	47	9.6	30	4.72	27	4.44	1.40
98SMS12AD02CM07	1554	D3	crust	16	21	11	-	-	innermost	0.801	0.602	0.030	26.94	15.92	0.14	0.08	1.12	0.069	0.063	1.66	0.40	3.01	0.38	0.315	243	921	47.1	197	40	9.90	37	6.1	39	7.8	23	3.52	21	3.17	1.69
98SMS12AD03CM01	1555	B	crust	40	55	27		botryoidal	bulk	0.485	0.394	0.013	22.31	14.40	0.13	0.07	0.81	0.064	0.063	1.67	0.44	8.79	2.34	0.280	308	981	45.1	207	38	9.80	40	7.0	45	10.0	32	4.87	29	5.03	1.55
98SMS12AD04CM01	1974	A	crust	30	47	12	tuff breccia	botryoidal	bulk	0.701	0.489	0.011	23.70	14.61	0.14	0.07	0.94	0.054	0.057	1.60	0.38	5.73	1.32	0.395	297	1304	44.2	196	36	9.16	33	6.3	41	8.9	29	4.33	26	4.48	1.62
98SMS12AD05CM01	1719	A	cobble	47	85	13	limestone	botryoidal	bulk	0.659	0.493	0.013	24.98	15.69	0.14	0.08	1.08	0.053	0.062	2.44	0.61	5.20	1.05	0.409	278	1043	42.3	193	36	9.17	36	6.5	41	8.9	28	4.24	25	4.30	1.59
98SMS12AD07CM01	1448	A	-	40	140	10	basalt, hyaloclastite, limestone	botryoidal	bulk	0.667	0.627	0.010	24.00	11.12	0.14	0.08	0.56	0.053	0.057	0.81	0.21	11.05	2.85	0.345	249	1042	33.1	147	28	7.16	25	5.2	33	7.3	23	3.47	21	3.60	2.16
98SMS12AD07CM02	1448	A1	-	6	8	5	-	-	upper-outer	1.546	0.727	<0.001	28.80	14.10	0.21	0.08	0.73	0.095	0.053	1.14	0.26	3.36	0.50	0.210	242	762	36.6	170	33	8.66	34	6.5	41	9.2	29	4.47	27	4.53	2.04
98SMS12AD07CM03	1448	A2	-	60	115	5	-	-	upper-inner	0.403	0.603	0.005	22.81	9.26	0.14	0.09	0.46	0.070	0.050	0.61	0.14	12.12	3.68	0.261	215	1212	30.9	137	25	6.52	21	4.8	29	6.6	21	3.20	19	3.27	2.46
98SMS12AD07CM04	1448	A3	-	12	20	10	-	-	lower-outer	0.532	0.496	0.023	23.16	10.12	0.15	0.08	0.43	0.061	0.053	0.63	0.24	11.66	3.40	0.442	266	1448	38.4	162	31	7.67	31	5.8	37	8.7	27	4.05	25	4.07	2.29
98SMS12AD07CM05	1448	A4	-	12	20	10	-	-	lower-inner	1.178	0.686	<0.001	28.32	15.07	0.16	0.08	1.12	0.075	0.060	1.36	0.32	2.79	0.34	0.392	260	1040	38.7	167	33	8.24	29	5.7	34	7.2	22	3.30	20	3.29	1.88
98SMS12AD08CM00	2060	C	crust	96	41	50	limestone	granule	bulk	0.509	0.367	0.038	21.60	13.46	0.15	0.07	0.91	0.055	0.060	1.51	0.45	9.64	2.60	0.526	365	1475	48.4	210	37	9.27	31	6.8	43	9.6	30	4.42	27	4.61	1.60
98SMS12AD09CM01	1796	A	crust	18	22	10	basalt	botryoidal	bulk	0.930	0.658	0.047	24.58	14.06	0.14	0.09	0.92	0.087	0.067	1.57	0.70	4.29	1.06	0.413	247	898	24.8	113	21	5.56	20	4.2	27	6.2	20	3.03	18	3.24	1.75
98SMS12AD10CM01	1499	A	crust	45	62	22	hyaloclastite	botryoidal	bulk	0.806	0.584	0.050	25.81	13.86	0.14	0.07	0.95	0.047	0.057	1.32	0.35	6.03	1.14	0.918	286	1206	40.1	176	33	8.61	34	6.3	41	9.5	30	4.56	26	4.61	1.86
98SMS12AD11CM01	1342	A	crust	45	75	15	hyaloclastito	botryoidal	bulk	0.753	0.848	0.044	27.31	11.68	0.14	0.10	0.67	0.055	0.053	0.95	0.29	9.33	2.07	0.554	262	843	36.6	169	31	8.05	30	6.1	39	9.0	29	4.42	26	4.65	2.34
98SMS12AD12CM01	1983	A	crust	20	21	17	basalt	granule	bulk	1.165	0.595	0.019	27.01	17.14	0.15	0.08	1.47	0.041	0.052	1.95	0.41	3.05	0.38	0.978	313	1524	44.6	200	38	9.50	33	7.2	43	9.2	29	4.48	25	4.45	1.58
98SMS12AD13CM01	1716	A	crust	32	53	11	conglomerate	botryoidal	bulk	0.837	0.525	<0.001	24.97	17.12	0.15	0.08	1.11	0.059	0.061	2.45	0.58	4.44	1.06	0.325	303	1080	43.2	197	38	9.65	34	7.2	45	9.7	30	4.59	27	4.56	1.46
98SMS12AD16CM01	2268	A	crust	60	75	53	basalt	botryoidal	bulk	0.345	0.336	0.061	18.12	15.98	0.11	0.07	1.01	0.035	0.055	4.04	1.10	7.18	1.54	0.486	269	931	38.1	169	31	8.30	30	6.0	37	8.4	26	4.00	24	4.32	1.13
99SMS12AD17CM15	1273	D	cobble	10	95	0	conglomerate	botryoidal	bulk	0.532	0.528	<0.001	23.42	13.38	0.14	0.08	0.77	0.057	0.066	1.26	0.30	8.61	1.83	0.248	258	1072	38.3	165	32	7.96	28	5.8	36	7.8	25	3.57	21	3.64	1.75
98SMS12AD18CM03	1157	C	nodule	14	16	10	basalt	granule	bulk	0.495	0.994	0.077	24.44	10.34	0.11	0.11	0.48	0.063	0.048	0.89	0.80	9.93	3.11	0.797	261	544	29.5	134	24	6.68	29	5.2	37	9.2	31	4.69	28	5.10	2.36

Appendix Table 5 (3) Results of chemical analysis of cobalt-rich crust

sample	sampling depth(m)	code	type of crust	thickness (mm) aver	max	min	substrate	condition of surface	analyzed part	Co %	Ni %	Cu %	Mn %	Fe %	Pb %	Zn %	Ti %	Mo %	V %	Si %	Al %	Ca %	P %	Pt ppm	La ppm	Ce ppm	Pr ppm	Nd ppm	Sm ppm	Eu ppm	Gd ppm	Tb ppm	Dy ppm	Ho ppm	Er ppm	Tm ppm	Yb ppm	Lu ppm	Mn/Fe
MS13-area																																							
98SMS13AD02CM02	1912	F	nodule	15	22	10	basalt	botryoidal	bulk	0.529	0.472	0.065	17.51	17.23	0.11	0.09	1.19	0.018	0.045	6.03	2.20	5.09	1.10	0.588	289	766	40.0	180	34	8.81	35	6.3	41	9.2	30	4.28	25	4.31	1.02
98SMS13AD03CM02	2527	B	crust	15	35	2	basalt	botryoidal	bulk	0.673	0.395	0.015	21.86	19.85	0.13	0.07	1.22	0.039	0.057	4.30	1.01	2.39	0.37	0.282	274	816	43.5	191	37	9.42	36	6.8	43	9.2	29	4.38	25	4.38	1.10
98SMS13AD05CM10	2033	C	crust	60	100	35	conglomerate	botryoidal	bulk	0.532	0.382	0.028	20.76	18.05	0.12	0.08	1.25	0.041	0.061	4.01	1.09	2.91	0.48	0.348	296	820	44.6	200	38	9.31	36	6.9	44	9.2	30	4.64	26	4.45	1.15
98SMS13AD06CM01	2289	A	crust	100	140	10	basalt	botryoidal	bulk	0.471	0.418	0.026	24.67	17.47	0.13	0.08	0.94	0.074	0.073	1.91	0.35	3.18	0.64	0.249	372	1154	62.6	268	51	12.80	46	8.8	53	11.0	34	4.89	28	4.50	1.41
98SMS13AD06CM02	2289	A1	-	15	25	10	-	-	outer	0.997	0.512	<0.001	27.09	17.85	0.14	0.07	1.14	0.069	0.065	2.39	0.42	2.66	0.24	0.264	322	877	52.5	232	44	11.50	43	8.0	51	11.0	35	5.11	30	5.13	1.52
98SMS13AD06CM03	2289	A2	-	10	15	5	-	-	inner(1)	0.603	0.434	<0.001	24.99	20.35	0.14	0.08	1.35	0.051	0.066	2.90	0.50	2.53	0.29	0.150	370	897	61.5	270	52	12.90	50	9.1	55	11.0	36	5.13	29	4.71	1.23
98SMS13AD06CM04	2289	A3	-	13	15	10	-	-	inner(2)	0.722	0.526	0.023	24.62	17.31	0.11	0.09	1.03	0.073	0.075	1.73	0.32	2.47	0.24	0.197	396	918	68.8	292	57	14.10	51	9.3	56	11.0	33	4.85	28	4.35	1.42
98SMS13AD06CM05	2289	A4	-	8	12	6	-	-	inner(3)	0.488	0.758	0.096	27.82	15.28	0.12	0.09	0.78	0.085	0.070	1.40	0.31	2.71	0.22	0.327	314	1581	56.5	235	46	10.90	37	7.3	43	8.5	26	3.78	22	3.45	1.82
98SMS13AD06CM06	2289	A5	-	10	10	10	-	-	inner(4)	0.418	0.505	0.092	26.32	19.14	0.15	0.09	1.04	0.070	0.079	1.82	0.39	3.16	0.42	0.431	407	1997	55.7	232	46	10.70	34	7.0	40	7.6	23	3.46	20	3.16	1.38
98SMS13AD06CM07	2289	A6	-	60	60	60	-	-	innermost	0.299	0.256	0.059	18.85	17.13	0.21	0.08	1.15	0.057	0.073	2.01	0.47	9.01	2.71	0.246	534	1840	71.0	301	51	12.00	45	9.0	57	12.0	40	5.89	34	5.76	1.10
98SMS13AD06CM08	2289	B	cobble	140	100	160	fragment	botryoidal	bulk	0.334	0.321	0.072	16.67	14.94	0.10	0.07	0.95	0.028	0.054	4.80	1.49	8.05	2.06	0.455	332	1006	49.2	210	39	9.87	35	6.8	42	9.1	29	4.08	24	3.94	1.12
98SMS13AD06CM09	2289	B1	-	5	15	0	-	-	outer	0.817	0.493	<0.001	24.21	18.67	0.13	0.07	1.04	0.061	0.069	2.88	0.55	2.44	0.40	0.146	328	809	50.6	227	44	11.30	44	8.2	52	11.0	36	5.31	30	5.15	1.30
98SMS13AD06CM10	2289	B2	-	10	15	8	-	-	inner(1)	0.651	0.423	0.004	23.02	19.13	0.12	0.07	1.49	0.035	0.058	4.33	0.96	2.40	0.26	0.166	319	932	50.2	217	43	10.60	38	7.5	47	10.0	31	4.59	27	4.52	1.20
98SMS13AD06CM11	2289	B3	-	20	15	25	-	-	inner(2)	0.647	0.401	0.060	20.93	17.49	0.09	0.07	1.33	0.038	0.053	4.46	1.34	2.05	0.21	0.606	276	994	43.6	187	37	9.37	31	6.5	40	8.4	27	3.95	24	4.06	1.20
98SMS13AD06CM12	2289	B4	-	20	15	25	-	-	inner(3)	0.445	0.419	0.130	22.80	20.71	0.09	0.09	1.02	0.056	0.069	3.22	0.94	2.36	0.32	0.649	290	999	47.6	236	51	13.10	47	8.7	49	10.0	32	5.09	30	5.00	1.10
98SMS13AD06CM13	2289	B5	-	90	100	80	-	-	innermost	0.124	0.109	0.033	11.41	12.06	0.11	0.06	0.89	0.021	0.046	3.28	1.07	17.27	5.56	0.324	332	1179	43.1	182	30	7.32	27	5.2	31	6.7	21	2.97	18	2.97	0.95
98SMS13AD07CM33	2469	G	cobble	70	90	40	basalt	botryoidal	bulk	0.399	0.364	0.064	21.98	16.97	0.10	0.08	1.04	0.041	0.078	3.11	0.78	4.45	0.87	0.417	330	1161	53.4	230	44	11.00	36	7.4	45	9.4	29	4.32	26	4.34	1.30
98SMS13AD08CM01	2054	A	cobble	30	60	10	basalt	botryoidal	bulk	0.439	0.377	0.033	19.69	15.73	0.09	0.07	0.98	0.041	0.062	3.00	0.79	6.16	1.56	0.376	295	832	43.8	190	37	9.16	33	6.4	40	8.4	27	3.88	22	3.79	1.25
98SMS13AD09CM07	1837	C	crust	50	60	40	limestone	botryoidal	bulk	0.379	0.322	0.017	18.20	17.67	0.09	0.07	1.20	0.031	0.048	5.70	1.74	3.51	0.82	0.404	298	673	42.5	188	37	9.53	39	6.9	43	9.7	31	4.43	26	4.70	1.03
98SMS13AD09CM13	1837	E	cobble	50	60	40	basalt	botryoidal	bulk	0.484	0.481	0.052	22.51	13.32	0.10	0.07	0.92	0.032	0.053	2.45	0.73	6.51	1.33	0.489	280	919	39.2	171	32	8.21	30	6.0	38	8.3	27	4.02	24	4.25	1.69
98SMS13AD10CM01	2333	A	fragment	27	30	25		granule	bulk	0.516	0.277	<0.001	20.98	18.28	0.12	0.07	1.32	0.038	0.056	4.14	0.89	2.10	0.27	0.161	316	834	48.2	203	40	10.20	40	7.5	48	10.0	32	4.71	28	4.67	1.15
98SMS13AD13CM01	2464	B	cobble	20	25	18	limestone	granule	bulk	0.769	0.451	0.015	23.43	16.09	0.10	0.06	1.18	0.037	0.045	3.58	0.93	2.45	0.26	0.248	270	807	41.3	184	36	9.10	33	6.7	41	8.6	28	4.13	24	4.11	1.46

Appendix Table 6 Sea-Water sound velocity for MBES

MS10		MS11		MS12		MS13	
Lat.	12°26.012'N	Lat.	10°54.017'N	Lat.	8°48.006'N	Lat.	8°18.07'N
Long.	158°22.036'E	Long.	161°04.902'E	Long.	163°30.03'E	Long.	160°25.125'E
Water depth (m)	Sound velocity ($m \cdot s^{-1}$)	Water depth (m)	Sound velocity ($m \cdot s^{-1}$)	Water depth (m)	Sound velocity ($m \cdot s^{-1}$)	Water depth (m)	Sound velocity ($m \cdot s^{-1}$)
10	1,540.9	10	1,541.8	10	1,542.4	10	1,542.4
20	1,540.8	20	1,541.9	20	1,542.5	20	1,542.4
35	1,541.0	35	1,542.3	35	1,542.8	35	1,542.9
50	1,541.2	50	1,542.5	50	1,543.0	50	1,543.5
70	1,541.3	70	1,542.8	70	1,543.3	70	1,543.8
100	1,539.9	100	1,542.1	100	1,542.5	100	1,541.1
200	1,515.3	200	1,510.6	200	1,498.5	200	1,503.8
300	1,497.9	300	1,494.3	300	1,494.0	300	1,493.4
500	1,486.7	500	1,487.7	500	1,488.9	500	1,491.3
700	1,485.6	700	1,486.4	700	1,486.1	700	1,487.3
1,000	1,483.9	1,000	1,484.6	1,000	1,485.1	1,000	1,484.6
1,500	1,485.8	1,500	1,486.1	1,500	1,486.6	1,500	1,486.9
2,000	1,491.5	2,000	1,491.2	2,000	1,491.6	2,000	1,491.8
2,500	1,498.5	2,500	1,498.5	2,500	1,498.5	2,364	1,498.7
3,000	1,506.3	3,000	1,506.4	2,750	1,502.4	2,750	1,506.3
3,500	1,514.5	3,500	1,514.5	3,500	1,514.4	3,500	1,514.4
4,000	1,523.0	4,000	1,523.0	4,000	1,522.9	4,000	1,522.4
4,500	1,531.9	4,267	1,527.6	4,470	1,531.1	4,470	1,531.1
5,000	1,540.9	5,000	1,540.9	5,000	1,540.9	5,000	1,540.9
5,458	1,549.4	5,458	1,549.4	5,458	1,549.4	5,458	1,549.4
Ave.	1,509.3	Ave.	1,509.3	Ave.	1,509.2	Ave.	1,509.9

Appendix Table 7 Weather and sea-state data

Monthly frequency distriction of wind direction in 1998

W.D.	CALM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Not Clear	Total
May	0	5	0	42	294	178	27	4	0	0	0	0	0	0	0	2	0	24	576
%	0.0	0.9	0.0	7.3	51.0	30.9	4.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	4.2	100.0
June	0	2	6	45	265	181	44	22	6	1	1	1	1	0	0	0	1	24	600
%	0.0	0.3	1.0	7.5	44.2	30.2	7.3	3.7	1.0	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.2	4.0	100.0
July	0	0	0	0	0	14	90	72	15	1	0	0	0	0	0	0	0	0	192
%	0.0	0.0	0.0	0.0	0.0	7.3	46.9	37.5	7.8	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0

Monthly frequency distriction of wind velocity in 1998

(W.V: m/sec)

W.V.	CALM	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20—	Total
May	1	0	3	2	3	1	12	25	83	133	127	98	49	29	8	2	0	0	0	0	0	0	576
%	0.2	0.0	0.5	0.3	0.5	0.2	2.1	4.3	14.4	23.1	22.0	17.0	8.5	5.0	1.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	100.0
June	1	0	5	4	10	18	54	76	95	120	106	84	23	2	0	0	1	0	1	0	0	0	600
%	0.2	0.0	0.8	0.7	1.7	3.0	9.0	12.7	15.8	20.0	17.7	14.0	3.8	0.3	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0	100.0
July	0	0	0	0	0	5	33	80	50	22	2	0	0	0	0	0	0	0	0	0	0	0	192
%	0.0	0.0	0.0	0.0	0.0	2.6	17.2	41.7	26.0	11.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0

Monthly frequency distriction of weather in 1998

Weather	Fine	Cloudy	Rain	Not clear	Total	Light Rain
May	21	2	1		24	12
%	87.5	8.3	4.2	0.0	100.0	50.0
June	13	8	4		25	10
%	52.0	32.0	16.0	0.0	100.0	40.0
July	7	1	0		8	4
%	87.5	12.5	0.0	0.0	100.0	50.0

Monthly frequency distriction of atmospheric pressure(daily average) in 1998

A.P.	-980	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019-	Not Clear	Total
May	0	0	0	0	0	0	0	0	3	34	96	151	163	100	26	2	0	0	1	0	576
%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	5.9	16.7	26.2	28.3	17.4	4.5	0.3	0.0	0.0	0.2	0.0	100.0
June	0	1	0	0	0	0	0	0	28	138	203	163	53	12	2	0	0	0	0	0	600
%	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	4.7	23.0	33.8	27.2	8.8	2.0	0.3	0.0	0.0	0.0	0.0	0.0	100.0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	16	49	65	43	17	1	1	192
%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	25.5	33.9	22.4	8.9	0.5	0.5	100.0

Monthly frequency distriction of no.1 swell direction in 1998

S.D.	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Not Clear	Total
May	0	0	8	147	144	20	8	0	0	0	0	0	0	0	0	0	249	576
%	0.0	0.0	1.4	25.5	25.0	3.5	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	43.2	100.0
June	0	0	27	181	119	4	1	0	1	1	0	0	0	0	0	0	266	600
%	0.0	0.0	4.5	30.2	19.8	0.7	0.2	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	44.3	100.0
July	0	0	0	0	15	87	10	0	0	0	0	0	0	0	0	0	80	192
%	0.0	0.0	0.0	0.0	7.8	45.3	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.7	100.0

Monthly frequency distriction of no.1 swell cycle in 1998

(W. V :m/sec)

S.C.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Not Clear	Total
May	0	0	0	0	0	13	113	148	40	11	2	0	0	0	0	0	249	576
%	0.0	0.0	0.0	0.0	0.0	2.3	19.6	25.7	6.9	1.9	0.3	0.0	0.0	0.0	0.0	0.0	43.2	100.0
June	0	0	0	0	1	29	151	147	15	4	0	0	0	0	0	0	253	600
%	0.0	0.0	0.0	0.0	0.2	4.8	25.2	24.5	2.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	42.2	100.0
July	0	0	0	0	5	29	65	13	0	0	0	0	0	0	0	0	80	192
%	0.0	0.0	0.0	0.0	2.6	15.1	33.9	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.7	100.0

Monthly frequency distriction of no.1 swell height in 1998

(S. H :m)

S.H.	0	1	2	3	4	5	6	7	8	9	10	Not Clear	Total
May	0	29	150	140	8	0	0	0	0	0	0	249	576
%	0.0	5.0	26.0	24.3	1.4	0.0	0.0	0.0	0.0	0.0	0.0	43.2	100.0
June	0	25	187	134	2	0	0	0	0	0	0	252	600
%	0.0	4.2	31.2	22.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	42.0	100.0
July	0	31	80	1	0	0	0	0	0	0	0	80	192
%	0.0	16.1	41.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.7	100.0

Monthly frequency distriction of degree of cloudiness in 1998

D.C.	0	1	2	3	4	5	6	7	8	9	10	Not Clear	Total
May	0	0	12	99	154	175	71	45	20	0	0	0	576
%	0.0	0.0	2.1	17.2	26.7	30.4	12.3	7.8	3.5	0.0	0.0	0.0	100.0
June	0	1	12	119	109	142	91	42	84	0	0	0	600
%	0.0	0.2	2.0	19.8	18.2	23.7	15.2	7.0	14.0	0.0	0.0	0.0	100.0
July	0	0	1	48	53	48	33	6	0	0	0	3	192
%	0.0	0.0	0.5	25.0	27.6	25.0	17.2	3.1	0.0	0.0	0.0	1.6	100.0

Monthly frequency distriction of no.2 swell direction in 1998

S.D.	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Not Clear	Total
May	0	0	6	11	10	3	0	0	0	0	0	0	0	0	0	0	546	576
%	0.0	0.0	1.0	1.9	1.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.8	100.0
June	0	0	7	9	8	24	15	0	2	0	0	0	0	0	0	0	535	600
%	0.0	0.0	1.2	1.5	1.3	4.0	2.5	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	89.2	100.0
July	0	0	0	2	0	0	2	3	0	0	0	0	0	0	0	4	181	192
%	0.0	0.0	0.0	1.0	0.0	0.0	1.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	94.3	100.0

Monthly frequency distriction of no.2 swell cycle in 1998

(W. V :m/sec)

S.C.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Not Clear	Total
May	0	0	0	0	1	11	6	12	0	0	0	0	0	0	0	0	546	576
%	0.0	0.0	0.0	0.0	0.2	1.9	1.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.8	100.0
June	0	0	2	2	4	32	11	14	0	0	0	0	0	0	0	0	535	600
%	0.0	0.0	0.3	0.3	0.7	5.3	1.8	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	89.2	100.0
July	0	0	0	0	7	4	0	0	0	0	0	0	0	0	0	0	181	192
%	0.0	0.0	0.0	0.0	3.6	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.3	100.0

Monthly frequency distriction of no.2 swell height in 1998

(S. H :m)

S.H.	0	1	2	3	4	5	6	7	8	9	10	Not Clear	Total
May	0	1	29	0	0	0	0	0	0	0	0	546	576
%	0.0	0.2	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.8	100.0
June	0	49	16	0	0	0	0	0	0	0	0	535	600
%	0.0	8.2	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	89.2	100.0
July	0	8	3	0	0	0	0	0	0	0	0	181	192
%	0.0	4.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.3	100.0