Chapter 7 Discussions and Recommendations

7 - 1 Formation, Development of Seamounts and Occurrence of Cobalt-rich Crusts

(1) Formation and development of seamounts

The four areas surveyed this year are; two marine areas to the east of the Caroline Islands and two marine areas to the northwest of the Caroline Islands, and these two groups of areas are far apart. The seamounts in each area has different morphology, and they were formed and developed under individually diverse environment. The diverse morphology and development history are reflected in the mode of occurrence of cobalt-rich crusts of each area. The outline of the history of formation and development of the seamounts in each area is as follows.

The seamounts of the MC11 and MS13 areas located to the east of the Carolines were formed as oceanic islands by alkali basalt volcanism during Mesozoic to early Paleogene. Cessation of the volcanism and erosion, and further subsidence sank the island below the sea surface and they became seamounts. The subsidence is considered, from the investigation of other seamounts in the vicinity, to have started in Miocene time. They are both guyots, but MC11 seamount summit is covered by unconsolidated sediments with common dome structure, while MS13 seamount summit is rugged with many pinnacles.

The seamount in MC12 area located to the northwest of the Carolines was formed as oceanic islands by alkali basalt volcanism during Mesozoic. After the cessation of volcanism and erosion, it gradually subsided developing reef on the summit, then in Paleogene it subsided rapidly and became a seamount. Controlled by the geologic structural changes caused by the movement of the seafloor, it is presently an oceanic ridge-type seamount with east-west trending axis.

The seamount in MC13 area located to the northwest of the Carolines was formed before Early Cretaceous of Mesozoic. It is believed to have been formed by alkali basalt volcanism as in the case of MC12 seamount, but evidences for this were not obtained by the present survey. After he cessation of the volcanism it subsided slowly, then rapidly subsiding in Paleogene and became a seamount. It moved to the present location accompanying the seafloor movement and during this process a new volcanism occurred in Late Cretaceous, and the steep cliff of the northern slope is considered to have formed at the time.

The western sea off the Carolines, areas MC02~Mc10 were surveyed in 1997, and the seamounts of these areas were divided into four groups by their age. The seamounts in MC11 and MC13 were grouped with those of areas MC08 and MC10 to seamounts formed before middle Paleogene, these four seamounts are distributed in the east-west direction north of the Caroline Ridge. the seamounts in MC11 and MS13 areas to the east of the Carolines continue to the seamount chain in the EEZ of the neighboring Marshall Islands. The composition and genesis of the basalt inferred from the results of the chemical analysis carried out this year are similar to those of the seamount chain of the western sea off the Marshall Islands.

(2) Occurrence of cobalt-rich crusts

In the MC11 area to the east of the Carolines, occurrence of thick cobalt-rich crusts was confirmed. Generally cobalt-rich crusts are thickly developed at water depth of 1,000 to 2,500m, but it was confirmed that in this area the seamounts with summit deeper than 2,500m had thick developed cobalt-rich crusts on the summit. Also generally the Co, Ni, Mn and other metal grade of the cobalt-rich crusts decreases with water depth, but in the seamount of MC11 area, the grade of the samples collected on the slope is somewhat lower, than those from the summit of seamounts in waters shallower than 2,000m, but the difference is small.

In the seamount of MS13 area, the samples containing thick crusts were concentrated near the pinnacles which occur sporadically on the summit. But, since MS13 seamount is considered to have been formed before Paleogene, there is a possibility of thick crust distribution under the unconsolidated sediment cover on the summit.

The seamounts in MC12 and MC13 areas were formed and subsided before Paleogene, and thick crusts reflecting the seamount age were collected. But the distribution of the thick crusts are limited and samples with mere coatings of manganese oxides occur widely. The topography of the seamounts in these two areas strongly reflect the geologic structure. Also there are evidences of repeated volcanism after submergence are found in the seamount of MC13 area. These factors and the localization of thick crusts do not appear to be directly related, but the distribution of crusts is considered to be affected directly or indirectly by the above factors.

7 - 2 Hydrothermal Activities

During the 1997 survey, pyrite-disseminated rocks were collected from the northern steep slope of the seamount in MC02. This indicated the possibility of hydrothermal sulfide deposit occurrence in the area. This year, survey was conducted in the MC02 area with the specific purpose of clarifying the state of hydrothermal activity of the area. The survey was centered around the foot of the northern steep slope of the seamount and the small depression on the northern side of the steep slope of the seamount. The area around the small depression was selected because hydrothermal activities were inferred from the geologic structure. The results did not show direct geological and biological evidence of the existence of hydrothermal activity, but it was confirmed that spring water flow associated with hydrothermal activity occurred in the small depression in after Pleistocene. Also mounds were found to exist under unconsolidated sediments in the small depression. Thus the possibility of the existence of hydrothermal sulfide deposits in the small depression was indicated aside from the steep northern slope of the seamount where pyrite disseminated rocks were sampled.

7 - 3 Future Work

Thick crusts and cobble crusts were confirmed in the seamounts of MC12 and MC13 areas, but the distribution is uneven. This is believed to be caused by the history of the seamount development and the geologic structure of the Western Sea of the Carolines, but the number of samples acquired is insufficient to thoroughly consider the problem. In the seas north to northwest of the Caroline Islands, the possibility of occurrence of thick crust ores is high and it is necessary to further conduct survey on the occurrence of the cobalt-rich crusts together with acquisition of data on geology and geologic structure of the area.

Cobalt-rich crusts are not well developed in waters below water depth of 2,500m, and the content of metal such as cobalt tend to decrease in further deep zones. But the summit of the seamount in MC11 area is deeper than 2,500m, and thick crusts were confirmed and the metal grade is not very different from those collected from other seamounts. Survey on occurrences and metal grades of cobalt-rich crust on deeper seamounts is rare, and future surveys are desired.

In MC02 area, the existence of hydrothermal deposits under unconsolidated sediments was indicated. Also in MS13 area seamount, thick crusts possibly occur under sediments. At the present state of survey methods, it is not possible to clarify material below the sediments. Thus survey methods for such purpose including seafloor drilling need to be established.

Chapter 8 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 cobalt-rich 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 Federated States of Micronesia was 22 days. This paper reports the results obtained in the EEZ of Micronesia.

There are many oceanic islands, atolls and seamounts in the waters of Micronesia. The survey was carried out in two areas; namely the eastern sea area to the south of Anewetak Atoll adjacent to the Marshall Islands, and the western sea area in the vicinity of Yap Province of Micronesia. The western sea area is located north of the 1997 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 microtopographic survey by SSS. Important samples were studied in laboratories on land by various methods including ore assay and thin section microscopy of rocks. These together with the results of onboard analysis provided the basis for integrated analysis of the resource.

Generalization of results of survey in 1997 and this year is shown in Table 8-1(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 areas were selected for cobalt-rich crust survey in the eastern sea, and two in the western sea (excluding the MC02 area which will be mentioned in this report for hydrothermal activity only). Of these, two in the eastern sea area and two in the western sea area are located in the EEZ of Micronesia. These seamounts were selected after considering the water depth, size, and the survey itinerary. In addition to the above, survey for hydrothermal activities was carried out in the MC02 area where indications for hydrothermal activity was discovered in the 1997 survey.

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 and the topographic characteristics of the seamounts. For all seamounts, the survey provided detailed topography and formed the basis for sampling and other subsequent studies.

In the four survey areas, two seamounts in eastern sea are guyots, one with dome-type summit, one with undulating rugged summit. The two seamounts in the western sea are oceanic ridge-type seamount and oceanic plateau-type seamount.

Table 8-1-1(1) Summary of Survey in Micronesia Federation Waters

Area		MC02	MC03	MC04	MC05	MC06	MC07	MC08	MC09	MC10	MC11	MC12	MC13	MS13
Location*1		9° 04′ N	6° 18′ N	(E)6° 12′ N (W)6° 15′ N	5° 31′ N	4° 23′ N	6° 05′ N	(N)10° 20′ N (S)10° 16′ N	(N)8° 21′ N (S)8° 06′ N	(N)10° 10′ N (S) 9° 45′ N	7° 30′ N	9° 20′ N	10° 20′ N	8° 15′ N
		141° 28′ E	141° 37′ E	(E)144° 45′ E (W)144° 22′ E	149° 13′ E	147° 58′ E	157° 26′ E	(N)156° 41′ E (S)156° 27′ E	(N)155° 26′ E (S)154° 58′ E	(N)148° 16′ E (S)148° 20′ E	161° 18′ E	146° 05′ E	145° 00′ E	160° 40′ E
Duration of survey		5 days	7 days	8 days	5 days	2 days	6 days	8 days	7 days	9 days	3 days	5days	6 days	7 days
・Topographic survey		529.6nm	831.4nm	914.9nm	613.4nm	252.5nm	592.5nm	649.1nm	861.2nm	1,042.2nm	310.6nm	827.0nm	701.1nm	845.0nm
・SSS survey.	Number of track line	2	1					1					1	1
Total length of track line		10.0nm	4.0nm					4.6nm					4.7nm	5.4nm
・Sampling														
AD	Number of samples	1	4				4				5	13	11	12
CB	Number of samples	2	8	18	8	8	6	16	12	17				
LC	Number of samples	4	4	3	1		5	3	1	3	1	1	3	3
Amount of crust samples (incl. Cobble crusts)		12.3kg	290.3kg	100.8kg		140.6kg	16.0kg	417.0kg	167.6kg	121.5kg	6.0kg	578.0kg	496.0kg	609kg
Amount of nodules			38.5kg	19.9kg		16.2kg	11.7kg	96.4kg	0.8kg	52.7kg		19.0kg	290.0kg	24kg
Amount of rocks & other material *3		167.4kg	77.5kg	203.2kg	113.8kg	123.1kg	42.1kg	68.1kg	60.5kg	40.8kg	16.0kg	364.0kg	208.0kg	191kg
・FDC observation	Number of track line		1	2			1	1	1	1	1	1	1	2
Total length of track line			5.7nm	8.8nm			6.3nm	4.5nm	2.3nm	4.8nm	2.1nm	2.4nm	2.2nm	3.9nm
Number of photographs			251	407			265	222	125	176	111	182	182	192
Video tapes			4 reels	5 reels			4 reels	4 reels	2reels	3 reels	2 reels	1 reels	1 reels	4 reels
・Surveyed water depth zone														
Topographic・SBP survey		1,080~3,700m	510~5,200m	100~3,800m	190~4,100m	740~4,500m	1,423~3,700m	1,583~5,600m	1,096~5,200m	1,442~4,800m	1,777~4,800m	1,141~4,100m	1,656~3,900m	1,387~5,100m
Sampling		1,268~3,335m	1,079~3,508m	301~3,876m	1,204~4,060m	1,421~2,636m	1,446~3,079m	1,682~5,208m	1,122~4,758m	1,593~4,366m	1,966~2,785m	1,150~3,798m	1,669~3,441m	1,801~4,069m
F D C			980~3,870m	178~3,636m			1,569~2,940m	1,969~2,284m	1,202~2,734m	1,948~3,525m	1,829~3,036m	1,179~2,514m	1,651~3,187m	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 8-1-1(2) Summary of Survey in Micronesia Federation Waters

	Area	MC02	MC03	MC04	MC05	MC06	MC07	MC08	MC09	MC10	MC11	MC12	MC13	MS13
Seamounts	Type	Plateau-figured	Ridge	(E)Part of ridge (S)Part of ridge	Shoal	Rugged guyot	Guyot	(N)Guyot (S)Guyot	(N)Rugged guyot (S)Pointed seamount	(N)Guyot (S)Guyot	Guyot	Ridge-figured	Plateau-figured	Rugged guyot
	Scale (km) *4		80 × 20km	(E)40 × 40km (W)80 × 30km	60 × 30km	70 × 40km	>50 × 20km	(N)24 × 15km (S)11 × 9km	(N)15 × 13km (S)15 × 8km	(N)33 × 19km (S)43 × 43km	13 × 23km	45 × 20km	40 × 35km	25 × 50
	Water depth distribution (m)	1,080~3,500m	510~3,900m	(E)950~3,800m (W)100~3,800m	190~4,000m	740~3,500m	1,423~3,800m	(N)1,583~5,500m (S)1,692~5,500m	(N)2,032~5,100m (S)1,098 × 5,100m	(N)1,442~4,800m (S)1,560~4,800m	1,777~4,800m	1,141~3,800m	1,656~3,800m	1,387~5,000m
	Areal extent of summit	>65 × 27km	53 × 15km		40 × 18km		>50 × 14km	(N)21 × 15km	(N)15 × 13km (S)15 × 8km	(N)>20 × 20km (S)40 × 35km	23 × 13km	18 × 2km	>35 × 35km	50 × 25km
	Slope inclination upper/middle/lower	7° /6°	16° /14° /5°	(E)12° /11° /12° (W)16° /11° /7°	14° /17° /15°	18° /16° /10°	8° /17° /5°	(N)19° /17° /12° (S)20° /18° /15°	(N)16° /17° /10° (S)27° /22° /7°	(N)20° /15° /7° (S)14° /10° /9°	13° /13° /9°	16° /12° /7°	10° /7° /5°	14° /11° /8°
	Summit~upper slope area (km²)	2,972	1,031	(E)379 (W)563	734	240	797	(N)374 (S)129	(N)363 (S)26	(N)463 (S)1,383	265	136	1,383	1,916
	Summit area (km²)	1,134	625	(E) (W)	504		278	(N)178 (S)38	(N)154	(N)334 (S)1,067	94	35	828	1,122
	Slope area (km²)	2,257	7,051	(E)1,256 (W)2,542	4,730	1,496	1,548	(N)1,353 (S)716	(N)1,008 (S)1,602	(N)1,906 (S)2,617	1,716	1,866	1,608	1,417
Geology	Summit		Reefal limestone extensive, foraminiferal limestone, basalt,	(E)Reefal limestone. (W)Reefal limestone	Reefal limestone.	Reefal limestone predominant, also basalt, hyaloclastite.	Mainly basalt, hyaloclastite, and reefal limestone observed in some	Basalt, hyaloclasetite, mudstone and foraminiferal	(North)Basalt. (South)Basalt and volcanic breccia.	Mudstone predominannt, basalt and conglomerate.	Basalt, foraminiferal limestone.	Reefal limestone predominannt.	Basalt, foraminiferal limestone, mudstone, chert, tuff.	Basalt, calcareous conglomerate, tuff.
	Slope	Generally basalt, foraminiferal limestone on upper slope.	Generally basalt, foraminiferal limestone on upper slope.	(East) Reefal limestone extensive, foraminiferal limestone, basalt on lower slope, (West) Reefal	Reefal limestone in upper-middle slope, Basalt, foraminiferal calcareous conglomerate predominant in	Basalt, hyaloclastite and foraminiferal limestone.	Basalt, hyaloclastite predominant, sandstone, mudstone and conglomerate confirmed.	Basalt, and hyaloclastite occur throughout the seamount, conglomerate in parts of upper,	(North) Basalt and conglomerate. (South) Generally basalt predominant, conglomerate in upper, hyaloclastite	Basalt, hyaloclastite, conglomerate, with mudstone and phosphate rock in some parts.	Basalt, calcareous conglomerate.	Basalt, tuff occur widely, mudstone and foraminiferal limestone also observed.	Basalt, mudstone, tuff.	Basalt, calcareous conglomerate, tuff breccia.
	Mode & occurrence	Thick crusts observed on summit small hill.	Crusts on eastern summit periphery to slope. Cobble crust collected from summit.	Crust on slope of both E and W seamount, but thin at several mm.	Crust generally underdeveloped.	Somewhat thick crust from middle N slope, but crusts generally underdeveloped.	Crusts distributed from summit periphery to upper slope, but generally thin.	Thick crusts from summit periphery to upper slope and also relatively thick crusts in middle・lower slope.	Crusts collected throughout slope. Average thin, but some relatively thick.	Thick crusts from summit periphery to middle slope of S seamount, particularly many thick crust on	Thick crusts from summit E periphery to upper slope and near pinnacles.	Crusts, cobble crusts exceeding 100mm on E-W trending ridge and ridge slope.	Thick crustsand cobble crusts near pinnacles on N and E side of summit.	Crusts and cobble crusts near summit pinnacles.
Cobalt rich crust	Substrate	Basalt, reefal limestone.	Basalt, reefal limestone, foraminiferal	Foraminiferal limestone, reefal limestone, basalt.	Basalt, hyaloclastite, tuff, sandstone, foraminiferal	Basalt, reefal limestone, tuff, hyaloclastite.	Basalt, tuff.	Basalt, hyaloclastite, mudstone, tuff.	Basalt, foraminiferal limestone, hyaloclastite.	Basalt, foraminiferal limestone, mudstone, hyaloclastite.	Basalt, foraminiferal limestone.	Basalt, reefal limestone, foraminiferal	Basalt, mudstone, tuff, foraminiferal limestone.	Basalt, limestones.
Thickness	Thickness variation with water depth *5													
	Summit	26	8.8	1.0	1.0	2.5	3.0	27.0	(North)7.8	5	8.5	18	50	52
	Upper slope		9.0	1.0	1.0	4.0	5.5	24.4	(South)8.0	33	37.5	91	10	1.5
	Middle slope	1	12.0	1.0	1.0	3.3	4.0	1.0	(North)5.0(South)6.5	13.5		12.7		
	Lower slope		4.0	1.0	1.0]	1.5		7.3	(South)5.0			101		
	Average thickness (mm) *6	21	8	1	1	3	5	20	7	20	36	40	45	46
	Max. thickness (mm) *7	50	47	20	1	20	14	90	23	155	55	190	140	160
	Number of sampling site *8	4	12	17	7	8	10	18	13	16	4	12	11	11
Grade	Co (%)	0.35	0.48	0.47		0.47	0.48	0.36	0.49	0.33	0.61	0.38	0.37	0.50
	Ni (%)	0.33	0.36	0.32		0.36	0.31	0.32	0.30	0.30	0.43	0.27	0.29	0.39
	Cu (%)	0.08	0.05	0.03		0.04	0.04	0.09	0.05	0.07	0.04	0.05	0.04	0.04
	Mn (%)	19.67	24.21	27.13		24.88	26.15	23.67	25.57	15.62	23.50	17.70	17.71	20.75
	Fe (%)	17.44	15.95	14.46		16.25	15.16	15.96	15.62	22.67	17.20	19.70	19.73	16.87
	Number of samples assayed *9	4	16	7		8	7	32	16	23	3	11	12	11
	Mode of bedrock (crust) exposure	Exposures on N steep slope, rear pinnacles on E side.	Exposures extensive on ridges and N slope, also observed on S steep slope.	On E seamount exposures on ridge summits and near pinnacles. On W seamount exposures observed on ridge	Exposures widely occur from upper to middle slope and parts of lower slope.	Exposures occur on topographic highs at 3 localities of summit, and steep parts of S and E slope.	Exposures at summit periphery and central pinnacles.	Exposures from summit periphery to upper slope of N and S seamounts. Exposures seen near summit pinnacles of	Exposures observed on summit protrusion of N seamount. Exposures widely occur from summit	Exposures from summit periphery to upper slope of S seamount. Exposures occur widely from summit	Exposures at upper E slope and pinnacles of E edge of summit.	Summit generally exposed. Exposures throughout slope except valleys.	Exposures observed on ridge on summit N side and continuing N slope.	Exposures distributed near summit pinnacles.
Assessment		Crust distribution limited, but relatively thick.	Distribution of thick crusts limited, but water depth shallow and exposure ratio good.	Water depth shallow, crust exposure ratio good, but thin.	young seamount and thus crusts undeveloped.	Crusts relatively thin, but Co, Ni grade high, and water depth shallow.	Thick crusts were not collected, but existence of such crusts is indicated by seafloor	Co grade low, exposure somewhat poor, but crust thick, seamount large, thus resources large.	Water depth deep, rugged topography, crusts relatively thin. But Co grade high.	Co, Ni grade low, but many crusts thick, exposure ratio high. Seamount large, thus resources	Co,Ni are high and thick crust distributing.	Co,Ni are a little low high but very thick crust distributing.	Co,Ni are a little low high but very thick crust distributing.	Co,Ni are high and 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 avera *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 co *9: Number of assayed samples

The water depth of the shallowest seamount summits ranges from 1,141m to 1,777m, the relative height from the base ranges from 2,140m to 3,610m and that of the MS10 area is the smallest with seamount area of 13 X 23km, and summit of the seamount in MC12 is the smallest with 35km2 of area; and the largest seamount is MC13 occupying an area of 40 X 35km. The largest summit area is that of MC13 with 1,382km2.

(MBES acoustic reflection intensity)

Each seamount has different form and thus the MBES acoustic reflection intensity map for each seamount has its unique characteristics.

The seamount in M11 is guyot with dome-shaped summit and the summit is all covered by unconsolidated sediments and thus pale color tone indicating low acoustic reflection intensity extends over the entire summit. But at pinnacles, summit periphery, and parts of the upper slope, however, dark tones appear.

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 MC12 seamount is a ridge-type without flat summit. The summit to the upper slope is steep and the distribution of sediments is limited, and thus dark tone is widely distributed.

The summit of the seamount in MC13 area is large and pale tone indicating unconsolidated sediments appears over the whole summit area. Dark parts are observed at the linear steep cliff in the northeastern to the eastern part of the summit and also near the pinnacles in the northern periphery. Also slightly higher acoustic pressure is observed in linear pattern parallel to the steep cliff.

The exposed bedrocks of seamounts are often covered by cobalt-rich crusts, 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 seamount with dome-shaped summit in MC11 area tend to have thicker unconsolidated sediments toward the central part of the summit. The maximum thickness is 60m. The vicinity of the pinnacles is exposed and thus the isopach contours have irregular shape.

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.

In MC12 area, the bedrocks are exposed generally on the summit and exposure occur scattered on the slope reflecting the ridge-type morphology, the unconsolidated sediments are thin.

The seamount of MC13 area has large rugged summit area, but it is generally covered by thick sediments. The thickest is 80m.

(SSS survey)

SSS survey was carried out on the seamounts of the MS13 and MC13 areas.

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.

The seamount in the MC13 area, SSS survey was carried out in the vicinity of the pinnacles in the northern summit periphery. With the exception of parts of the foot of the western slope of the pinnacles, pebbles were recognized on the bedrock exposures of step topography.

(Sampling)

Sampling by dredges and a large corer was carried out at 49 sites in four areas, MC11 to MC13 and MS13. Cobalt-rich crusts were recovered from 39 sampling points, of which crusts or cobble crusts were collected from 34 points and nodules were recovered from two points by large corer and three points by dredge. Ores from 37 samples from 30 sites were assayed. 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, MC11~MC13 and 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 samples from MC11 and MS13 are strongly weathered and fresh samples were not obtained. But fresh blackish gray samples were recovered from the seamounts in MC12 and MC13 areas.

Conglomerate samples with foraminiferal limestone matrix containing foraminiferal limestone and basalt pebbles were recovered from the summit to the slope of each seamount. In MC11 and MS13 seamounts most of the conglomerate have relatively good consolidation, while those of MC12 and MC13 seamounts are mostly fragile and merely cementing the pebbles. At the summit of MC12 seamount consists of reefal limestone indicating the formation of coral reef, and basalt was not recovered. Calcareous mudstone was collected from the MC12 and MC13 areas.

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 MC12 seamount.

From the summit of MC13 seamount, chert has been collected and the radiolaria fossils in this chert was identified to be Middle Cretaceous in age.

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

(Seafloor observation)

Seafloor was observed by FDC along five 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 of the upper slope terrace of MS13 area, but cobble crusts and nodules were distributed on the sediments. In the MC12 seamount, angular pebbles considered to be talus deposits were seen on the gentle slope. In the seamount of the MC10 area, cobble crusts were observed to be mixed with angular fragments. And in MC12 area, parts of seamount slope were observed to be covered by angular pebbles, but occurrence of crusts was confirmed in the exposed parts.

(Thickness of cobalt-rich crusts)

Thick crusts occur on each seamount. The average thickness of the samples recovered from each seamount ranges more than 35mm, and the maximum thickness of the samples of each seamount (except MC11) exceeds 140mm.

The crusts in many parts of the seamounts in MC12 and MC13 areas are less than 10mm in average thickness, but there are parts of these seamounts where the average exceeds 100mm.

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.

The crusts of the seamount of the MC11 area is 36.1mm in average thickness. It is the thinnest average of the four areas, and regarding the maximum thickness those exceeding 55mm and 100mm were not obtained. The distribution is also heterogeneous. But crusts also occur below 2,700m water depth, and it was confirmed that thick crusts occur even on small seamounts most of which are deeper than 2,500m of water depth.

(Chemical analysis of cobalt-rich crusts)

Thirty-seven samples were selected from cobalt-rich crust samples collected at 30 sites in four areas of MC11~MC13 and MS13, and these 37 samples were chemically analyzed for 29 elements. The number of analyzed samples including layer analysis was 69 samples. The average grades of the major elements of the four areas are; Co 0.45%, Ni 0.35%, Cu 0.04%, Mn 20.0%, Fe 17.6%. The grade differs considerably by the area. With the exception of Fe, samples from the two areas in the Eastern Sea tend to have somewhat higher grade compared to those from the two areas in the Western Sea. The content of all elements of the cobalt-rich crusts samples collected this year from the Western Sea is lower than the results from MC02~MC10 areas in the northwestern~western seas surveyed in 1997.

The rate of growth of crusts was calculated using cobalt-rich crusts with coral nucleus from MC12 area. The result was cobalt-rich crusts grew from about 20,000BP to the present at a rate of 5~10/Ma. This figure is relatively large for crust layer growth in general.

(Mode of occurrence of cobalt-rich crusts)

The occurrence of crusts and cobble crusts with average thickness exceeding 35mm is confirmed from all four areas. In the three areas excluding MC11, the maximum thickness is 140~190mm.

Based on results in 1997 and this year, The characters of condition of cobalt-rich crust in this area of sea are arranged follows.

- The crust is well developed and thick on guyots older than Paleogen, and those on seamounts younger than Paleogene are thin.
- The thickness of the crust on seamounts younger than Paleogene depends on topography and geology than the age.
- The crust on pinted seamoutains which slopes are shallow, is very thin.
- The average grade of the majar elements also vary by area. Cu contain is higher at MC02, MC08 and MC10areas and Co, Mn contains are lower than at other areas. The Co contain at areas which are closed to FEZ of the Repablic of Marshall Islands, are high, 0.51~0.61%. In the northern part of its west area, the Co contain is lower 0.35~0.41%, and in the southern part, it is also lower 0.38~0.48%.

To summarize the above conditions regarding the occurrence of cobalt-rich crusts in the survey area, MC11 and MS13 areas which are closed FEZ of the Republic of Marshall Islands, with large ore reserves are prospective. MC12 and Mc13 areas are next to MC11 and MS13 areas. In the whole, the old seamounts of northern part of this area of sea, are asscessed high on the basis of cobalt-rich crust occurrence.

(Hydrothermal activity)

Indications regarding occurrence of hydrothermal activities were obtained by the 1997 survey in MC02 area. This year survey of this area was carried out in order to clarify the state of hydrothermal activity. Direct evidences concerning hydrothermal activity were not obtained by the present survey, but stratigraphic relations indicating the occurrence of hydrothermal activities in the unconsolidated sediments in the small depression on the northern side of the seamount was confirmed, and mound topography was observed under the unconsolidated sediments. As a result, the possibility of hydrothermal sulfide deposit occurrence under the sediments in the northern small depression was shown aside from the foot of the steep northern slope where pyrite disseminated rocks were collected in 1997.

(Consideration)

The MC13 and MC12 areas are located in the sea northwest of the Caroline Islands. The seamounts in these areas were formed in Mesozoic~early Paleogene, and it was proven by the present survey that they are a part of the seamount chain extending in the east-west direction on the northern side of the Caroline Islands. In these seamounts, the possibility of the occurrence of thick cobalt-rich crusts is high, and thick crusts and cobble crusts have been collected from the two areas. The thickness of the cobalt-rich crusts, however, vary widely and the reason for this variation is considered to be volcanic activities after the formation of the seamounts and the effect of geologic structure. For investigating the occurrence of cobalt-rich crusts in this area, further acquisition of geologic and geologic structural data is necessary.

Also the chemical nature, namely the metal content, of the crusts vary widely by area, and further survey is desirable for clarifying the trend of ore grades and to understand the occurrence of crusts in the whole waters of Micronesia.

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Appendix

<Analysis of biogenic materials in bottom sediments>

Several to 20cm-thick organic-appearing, jelly-like material with sulfur odor was collected as an intercalation in viscous mud in all samples by LC from three site in the northern depression.

If this material is really organic, the following is inferred;

1. The rate of deposition in the area was very high and organic matter deposited on the seafloor was buried before transformation to inorganic matter.

Or

2. Reaction took place under anaerobic environment forming organic matter.

The tests shown in Table 1 were conducted in order to confirm the organic nature. The samples used for the tests are shown in Table 2. The results of analysis are shown in Table 3.

① Microscopic observation of biogenic material
By optical microscopy, plant planktons were observed with high frequency in samples 1 and 2, while in comparative sample 3 mineral grains were predominant and the frequency of plant planktons appearance was low. Observed plant plankton was all diatom of genus Ethmodicus.

② Chemical analysis

- Organic carbon content
All samples contain less than 1% organic carbon, and have low organic content.

- Biogenic silicates (opal)
The opal content is lowest in sample 3 at 18.6%, while the other two contain over 30%. The total silica content is 61.1~64.0% for samples 1 and 2 respectively, indicating the existence of mineral-origin silica in amount similar to opal.

- Calcium carbonate
Calcium carbonate content is highest in sample 3 at 51.0%, while samples 1 and 2 contain 20.3 and 15.6% respectively, indicating reverse relation to biogenic silica content.

③ Dyeing nucleic acid (total bacilli: number of bacteria cells)
Least number of cells are contained in sample 3 at 1.35×10^7cells/Dg, and the largest is in sample 1 at 2.50×10^7cells/Dg. But in this case, the content of samples 1 and 2, and of the comparative sample 3 is not very different.

④ Physical properties of soil
Water content of all samples is 60~70%.
The specific gravity of all samples was within the range of 2.19~2.49g/cm^3.

It was clarified from the above that the jelly-like or organic-appearing fine soil was not very

Table 1 Analysis items

Items	Specify
Microsorpic observation	Observation, Photographs
Chemical analysis	Organic maturity oxygen
	Life origin silicic acid (opal)
	Calcium carbonite
Dyeing nucleic acid	DAPI dyeing
Soil physics test	Water content
	Specific gravity

Table 2 Sample list

Sample No.	sampling date	sampling point	Sampling depth	description
Sample No.1 (98MCO2LC08)	1998.6.26	9° 13.974N 141° 34.568E	190cm	greenishi gray jelly-like
Sample No.2 (98MCO2LC14)	1998.7.12	9° 13.757N 141° 32.402E	175cm	greenishi gray jelly-like
Sample No.3 (ditto)	(ditto)	(ditto)	176cm	grayish porous

* No.3 is compare sample.

Table 3 Results of Analysis

	Item	Unit	Sample No.1	Sample No.2	Sample No.3
Oranic maturity oxgen and total nitrogen	TOC	mg/Dg	7.29	6.92	4.73
	TN	mg/Dg	0.91	0.8	0.59
	TOC	%	0.729	0.692	0.473
	TN	%	0.091	0.08	0.059
	C/N		8.01	8.65	8.02
Life origine silicic acid and total silica	Total silica	%	61.1	64	37.9
	Opal	%	31.6	30.1	18.6
Total calcium carbonate	CaCO3	%	20.3	15.6	5.1
Number of bacteria cell	Total cell	cells/Dg	2.50E+07	1.97E+07	1.35E+07
	SD		1.21E+07	6.34E+06	6.21E+06
Soil physics test	Water contain	%	67.6	64.5	62.9
	Specific gravity	g/cm^3	2.19	2.3	2.5

different chemically and physically from the general bottom clay collected simultaneously. Thus the organic-appearing material is not organic. Also the total number of bacteria is almost the same as that of ordinary bottom clay, and the possibility of anaerobic bacteria activity in the formation of organic-appearing material is considered to be low.

Supplement

The above organic-appearing material is different from material derived from minerals in that it has high water content and high elasticity. The possibility of organic carbon was denied, but the possibility of some type of biogenic origin still remains.

Typical biogenic material is opal, its origin is diatoms, radiolaria, bone fragments of sponges, and others. Sediments rich in the remains of the above are called siliceous ooze (siliceous clay).

The analytical results show that the opal content of samples 1 and 2 is clearly high compared to other constituents. The opal content of sample 3 is about 1/2 of that of samples 1 and 2. Thus the samples in question can be characterized by high opal content. This is not contradictory to the results of microscopy that samples 1 and 2 contain many remains of diatom consisting of genera Ethmodicus, Coscinodiscus, and Asteromophalus, while sample 3 contain few such fossils. From the above, it is clear that samples in question contain large percentage of opal, and that it is composed of the remains of diatom, particularly that of Ethmodiscus. The above results indicate that the samples investigated are ethmodiscus ooze.

Ethmodiscus ooze containing many genus Ethmodiscus (mainly Ethmodiscus rex) have been reported widely (Wieseman and Hendey, 1953; Mikkelsen, 1977; Tanimura, 1981). This sediment occur widely in equatorial deep seafloor , but the reason and process of sedimentation is not clear (Mikkelsen, 1977). It is interesting to note that Ethmodiscus rex is distributed widely at present in the Pacific ocean, but the its density is reported to be only one cell/2-50m3 (MC Hugh, 1954; Belyayeva, 1968). Such low density diatom remains becoming a main component at certain period is a "Ethmodiscus rex" problem which is still not solved.

[Appendix]

Appendix Table 1(1) Summary of Sampling Results

No.	Sample No.	Sampling site		MBES	CTD-BT	CTD-BR	Topographic division	Crust type	Amount of samples (kg)	LC core length (cm)	Crust thickness (mm)			Type of substrates, nuclei	Type of rocks・rock fragments bottom sediments (LC)
		Latitude	Longitude	Depth(m)	Depth(m)	Depth(m)					Max	Min	Av.		
1	98SMC11LC01	7° 29.996′ N	161° 15.022′ E	2,432	2,422	2,389	Western summit periphery			71					Foraminiferal sand, basalt.
2	98SMC11AD02	7° 32.646′ N	161° 19.084′ E	2,656	2,609	2,492	Upper northern slope	Crust.	0.134		3	1	2	Basalt	Basalt, limestone, pumice.
3	98SMC11AD03	7° 29.774′ N	161° 20.221′ E	2,155	2,110	1,981	Western summit periphery	Crust, crust fragments.	2.520		55	8	40	Basalt	Basalt, limestone, pumice.
4	98SMC11AD04	7° 27.563′ N	161° 16.243′ E	2,785	2,822	2,526	Upper southern slope								Basalt, conglomerate, pumice.
5	98SMC11AD05	7° 28.580′ N	161° 20.028′ E	2,413	2,377	2,246	Western summit periphery	Crust fragments.	0.560		40	10	15		Pumice.
6	98SMC11AD06	7° 29.487′ N	161° 21.311′ E	2,679	2,607	2,526	Upper southern slope	Crust, crust fragments.	2.910		55	10	35	Basalt	Basalt, conglomerate, pumice.
1	98SMC12LC01	9° 22.013′ N	146° 20.797′ E	3,798	3,788	3,773	Lower eastern slope			98					Ooze, mudstone.
2	98SMC12AD02	9° 19.712′ N	145° 56.512′ E	2,158	2,160	1,961	Middle SW slope	Nodules	0.015		12	1	3	Basalt	Basalt, tuff.
3	98SMC12AD03	9° 20.421′ N	145° 58.291′ E	1,929	1,903	1,768	Upper SW slope	Crust, cobble crust, nodule	128.060		150	1	91	Limestones	Basalt, tuff, limestones.
4	98SMC12AD04	9° 20.855′ N	145° 59.877′ E	1,424	-	-	Northwest periphery	Nodules	15.200		25	5	15	Crust fragment	Coral limestone, limestones.
5	98SMC12AD05	9° 20.099′ N	146° 03.094′ E	1,260	1,218	1,269	Central summit	Crust, crust fragments, cobble crust.	7.610		50	1	26	Limestones	Coral limestone, limestones.
6	98SMC12AD06	9° 21.478′ N	145° 49.630′ E	2,518	2,474	2,260	Lower NW slope	Crust, crust fragment, cobble crust, nodule.	173.360		190	1	101	Hyaloclastite	Tuff, calcareous conglomerate, mudstone.
7	98SMC12AD07	9° 21.740′ N	145° 54.971′ E	2,213	2,159	1,915	Middle NW slope	Crust fragment, nodule.	5.790		65	2	7		Tuff, basalt.
8	98SMC12AD08	9° 21.483′ N	145° 59.099′ E	1,736	-	-	Upper NW slope	Crust, crust fragment.	8.170		70	5	45	Tuff	Tuff.
9	98SMC12AD09	9° 20.004′ N	146° 04.590′ E	1,150	1,106	1,083	Central summit	Crust fragment, cobble crust.	25.080		40	1	13	Coral limestone, limestones.	Coral limestone.
10	98SMC12AD10	9° 17.483′ N	146° 07.611′ E	2,309	2,311	2,063	Middle SE slope	Crust, crust fragment.	0.470		25	1	10	Limestones, tuff.	Limestones, tuff, basalt.
11	98SMC12AD11	9° 21.102′ N	146° 06.798′ E	2,392	2,256	2,278	Middle NE slope	Crust, crust fragment, nodule.	0.530		30	1	8	Tuff, basalt.	Limestones, tuff, basalt.
12	98SMC12AD12	9° 25.340′ N	146° 03.205′ E	2,944	2,931	2,832	Lower northern slope								Limestones, tuff, basalt.
13	98SMC12AD13	9° 17.498′ N	146° 07.602′ E	2,308	2,309	2,017	Middle SE slope	Crust, crust fragment.	1.520		20	1	5	Limestones.	Limestones, tuff, basalt.
14	98SMC12AD14	9° 21.966′ N	145° 52.572′ E	2,326	2,289	1,970	Middle NW slope	Crust, crust fragment.	231.400		180	12	45	Limestones.	Limestones, tuff, basalt.
1	98SMC13LC01	10° 20.039′ N	145° 19.996′ E	3,441	3,462	3,413	Lower eastern slope	Nodules	0.047	140	7	1	5	Phosphorite	Foraminiferal sand.
2	98SMC13AD02	10° 25.340′ N	144° 52.673′ E	2,319	2,299	2,133	Western summit periphery	Crust, cobble crust, nodule	5.490		25	1	10	Mudstone	Mudstone, limestone, basalt, tuff.
3	98SMC13AD03	10° 25.358′ N	144° 57.924′ E	1,795	1,750	1,684	Western central	Cobble crust, nodule.	136.000		120	0	32	Phosphorite, limestones.	Limestone.
4	98SMC13AD04	10° 26.797′ N	145° 00.296′ E	2,069	2,298	2,034	Northern summit periphery								Mudstone, basalt.
5	98SMC13AD05	10° 27.181′ N	145° 01.135′ E	2,799	2,798	2,473	Upper NE slope	Crust fragment.	0.205		30	3	15	Not collected.	Mudstone, basalt.
6	98SMC13AD06	10° 19.407′ N	145° 06.605′ E	2,363	2,347	2,116	Southern summit periphery	Crust, crust fragment, cobble crust.	200.400		105	0	50	Calcareous conglomerate, basalt.	Tuff.
7	98SMC13AD07	10° 18.208′ N	145° 02.120′ E	2,042	2,043	1,849	SE Pointed summit	Crust fragment, cobble crust, nodule.	130.870		100	0	31	mudstone, basalt, limestones.	Limestone, basalt, tuff.
8	98SMC13AD08	10° 15.301′ N	145° 04.231′ E	2,538	2,499	2,354	Upper SE slope	Cobble crust.	4.000		15	1	4	Basalt	Basalt, foraminiferal limestone.
9	98SMC13LC09	10° 22.706′ N	145° 04.529′ E	2,247	2,232	2,219	Northeast summit periphery			0					
10	98SMC13LC10	10° 19.996′ N	145° 02.513′ E	2,149	2,141	2,131	Southern summit periphery			129					Foraminiferal sand.
11	98SMC13AD11	10° 26.607′ N	145° 03.166′ E	3,020	2,974	2,550	Upper Northeast slope	Crust fragment.	0.003		7	2	5	Not collected.	Basalt, tuff, mudstone.
12	98SMC13AD12	10° 24.305′ N	144° 59.979′ E	2,007	1,975	1,900	Southern central summit	Cobble crust, nodule.	72.400		140	0	15	Tuff, basalt, chert.	Limestone, basalt, tuff.
13	98SMC13AD13	10° 27.883′ N	144° 53.286′ E	2,541	2,458	2,343	Upper northwest slope	Crust	3.630		3	1	2	Basalt	Basalt.
14	98SMC13AD14	10° 26.521′ N	144° 52.484′ E	2,197	2,163	2,067	Northwest summit periphery	Nodules	226.800		5	2	3	Limestone, tuff, mudstone etc.	

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)
1	97SMC02LC01	9° 14.967′ N	141° 35.009′ E	3,306	3,256		Foot of SE slope		35.600	215	-	-	-		
2	97SMC02AD02	9° 08.457′ N	141° 37.456′ E	1,954	1,933	1,370	Upper northern slope				-	-	-		
3	97SMC02CB03	9° 10.162′ N	141° 32.235′ E	3,255	3,335	3,320	Lower northern slope	Stain	81.200		<1	<1	<1		
4	97SMC02CB04	8° 58.209′ N	141° 38.744′ E	1,487	1,558	1,268	Pinnacle on SE summit	Crust	58.700		50	<1	30		
5	97SMC02LC05	8° 58.602′ N	141° 38.423′ E	1,631	1,636		Pinnacle on SE summit	Crust	0.190		35	30	32		
6	97SMC02LC06	8° 58.516′ N	141° 33.921′ E	1,486	1,482		Pinnacle on SE summit	Crust	1.080		25	20	22		
7	97SMC02LC07	9° 07.601′ N	141° 41.942′ E	1,421	1,412		Northern summit periphery		1.900	23	-	-	-		
8	98SMC02LC08	9° 13.974′ N	141° 34.568′ E	3,558	3,540	3,533	Northern depression			328	-	-	-		Ooze
9	98SMC02LC09	9° 14.158′ N	141° 33.496′ E	3,554	3,505	3,489	Northern depression			95	-	-	-		Ooze
10	98SMC02AD10	9° 10.403′ N	141° 31.052′ E	3,347	3,311	3,278	Lower northern slope	Nodule.	0.029		5	1	3		Tuff, Basalt, Limestone
11	98SMC02AD11	9° 10.444′ N	141° 33.920′ E	3,280	3,248	3,220	Lower northern slope								Tuff, Basalt, Limestone
12	98SMC02AD12	9° 14.313′ N	141° 33.277′ E	3,547	3,494	3,487	Northern depression								Tuff, Basalt, Limestone
13	98SMC02LC13	9° 10.827′ N	141° 33.984′ E	3,280	3,266	3,258	Lower northern slope			262					Ooze
14	98SMC02LC14	9° 13.757′ N	141° 32.402′ E	3,562	3,513	3,500	Northern depression			262					Ooze
15	98SMC02CB15	9° 09.790′ N	141° 33.464′ E	3,159	3,175	2,801	Middle northern slope								Limestone, Basalt
1	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		Calcareous clay (poto:sand, nodule)
2	98SMS13AD02	8° 19.567′ N	160° 35.808′ E	1,927	1,912	1,799	Western summit	Crust, nodule.	0.26		22	1	6	Basalt.	Basalt, tuff, limestone.
3	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.
4	98SMS13AD04	8° 15.237′ N	160° 30.240′ E	2,859	2,901	2,333	Upper western slope							-	Basalt, tuff breccia, limestone, pumice.
5	98SMS13AD05	8° 11.657′ N	160° 33.630′ E	2,033	-	-	Western summit	Crust, nodule.	145.58		100	1	28	Basalt, calcareous conglomerate.	Calcareous conglomerate, basalt, pumice.
6	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.
7	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, basalt.	Pumice.
8	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.
9	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.	Foraminiferal sand.
10	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.
11	98SMS13LC11	8° 12.821′ N	160° 36.989′ E	2,029	2,005	2,002	Eastern summit			0					
12	98SMS13LC12	8° 11.959′ N	160° 33.343′ E	2,079	2,082	2,077	Western summit			0					
13	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.
14	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.
15	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 MC11 Area

Sample number	Rock type	Water depth (m) On bottom	Water depth (m) Off bottom	Substrate	Description
98 AD 03	Crust substrate.	2,095	1,866	Basalt	Weathered brown
AD 03	Rocks	2,095	1,866	Basalt	Coarse grained. Pyroxene phenocrysts.
AD 03	Rocks	2,095	1,866	Foraminiferal limestone	Pelitic, compact, fragile.
AD 06	Crust substrate.	2,592	2,511	Basalt	Fine grained, porous. Acicular plagioclase phenocrysts notable.
AD 06	Rocks	2,592	2,511	Basalt	Phyric, fine grained, porous. Vesicles filled by opal, zeolite.
AD 06	Rocks	2,592	2,511	Calcareous conglomerate	Contain subangular basalt pebbles. Matrix pelitic, fragile.
AD 02	Crust substrate.	2,594	2,477	Basalt	Fine grained, compact, but porous. Pyroxene, plagioclase phenocrysts.
AD 02	Rocks	2,594	2,477	Basalt	Fine grained, compact, but porous. Pyroxene, plagioclase phenocrysts.
AD 04	Rocks	2,807	2,511	Basalt	Fine grained, compact, phyric.
AD 04	Rocks	2,807	2,511	Calcareous conglomerate	Contain subangular basalt pebbles. Matrix phosphatized.

Appendix Table 2 (2) Rock Samples from MC12 Area

Sample number	Rock type	Water depth (m) On bottom	Water depth (m) Off bottom	Substrate	Description
98 AD 09	Congromeratic crust substrate	1,091	1,068	Reefal limestone	Crust cement coarse, soft limestone pebbles containing biologic fragments.
AD 09	Rocks	1,091	1,068	Reefal limestone	Coral structure, coarse, soft.
AD 05	Crust substrate	1,203	1,254	Reefal limestone	Coral structure, remnants. Contain nummulites.
AD 05	Rocks	1,203	1,254	Reefal limestone	Coral structure, remnants. Contain nummulites, gastropods.
AD 04	Rocks	1,424	1,372	Reefal limestone	Coral structure, remnants confirmed.
AD 04	Rocks	1,424	1,372	Foraminiferal limestone	Coarse grained, fragile.
AD 08	Crust substrate	1,736	1,543	Tuff	Pumiceous tuff. Coarse, soft, strongly altered.
AD 08	Rocks	1,736	1,543	Tuff	Pumiceous tuff. Coarse, soft, strongly altered.
AD 03	Congromeratic crust substrate	1,888	1,753	Reefal limestone	Crust-coated basalt, contain rounded tuff pebbles. Biologic fragments mixed.
AD 07	Rocks	2,144	1,900	Basalt	Rock fragments. Porous.
AD 07	Rocks	2,144	1,900	Tuff	Subrounded pebbles. Strongly weathered, fragile.
AD 02	Nodule nucleus.	2,145	1,946	Basalt	Aphyric, vitreous.
AD 02	Rocks	2,145	1,946	Basalt	Aphyric, vitreous.
AD 02	Rocks	2,145	1,946	Tuff	Mainly pumice.
AD 11	Nodule nucleus.	2,241	2,263	Basalt	Aphyric, porous.
AD 11	Rocks	2,241	2,263	Basalt	Aphyric, porous.
AD 11	Rocks	2,241	2,263	Tuff breccia	Contain pumice and small basalt fragments. Coarse, soft.
AD 11	Rocks	2,241	2,263	Reefal limestone	Coarse grained, contain biologic fragments, but well consolidated, hard.
AD 14	Crust substrate	2,274	1,955	Calcareous conglomerate	Contain angular basalt pebbles. Matrix merely cementing rock fragments.
AD 14	Rocks	2,274	1,955	Basalt	Rock fragments. Phyric, porous.
AD 14	Rocks	2,274	1,955	Basalt	Rock fragments. Aphyric, vitreous. Parts hyaloclastized.
AD 14	Rocks	2,274	1,955	Tuff	Porous. Contain pumice.
AD 14	Rocks	2,274	1,955	Calcareous conglomerate	Small angular and subrounded basalt pebbles. Matrix not phosphatized, but hard.
AD 13	Crust substrate	2,294	2,002	Reefal limestone	Coral structure confirmed.
AD 13	Rock	2,294	2,002	Basalt	Rock fragments, aphyric, porous.
AD 13	Rock	2,294	2,002	Tuff	Rock fragments, coarse grained, strongly altered, soft.
AD 13	Rock	2,294	2,002	Reefal limestone	Contain biologic fragments, porous. But hard.
AD 13	Rock	2,294	2,002	Foraminiferal limestone	Pelitic, contain biologic fragments, soft.
AD 10	Rock	2,296	2,047	Basalt	Aphyric, vitreous. Surface weathered, but innerside fresh.
AD 10	Rock	2,296	2,047	Tuff	Contain pumice. Coarse, soft. Weathered, fragile.
AD 10	Rock	2,296	2,047	Reefal limestone	White, coarse, soft.
AD 10	Rock	2,296	2,047	Foraminiferal limestone	Coarse grained, porous, but phosphatized and hard.
AD 06	Crust substrate	2,459	2,245	Hyaloclastite	Consist of aphyric, vitreous small basalt fragments.
AD 06	Rock	2,459	2,245	Calcareous conglomerate	Contain angular basalt pebbles. Matrix phosphatized.
AD 06	Congromeratic crust substrate	2,459	2,245	Mudstone	Solidified ooze, nodules attached.
AD 06	Nodule nucleus.	2,459	2,245	Mudstone	Solidified ooze.
AD 06	Nodule nucleus.	2,459	2,245	Hyaloclastite	Consist of aphyric, vitreous small basalt fragments.
AD 12	Rock	2,916	2,817	Basalt	Mixture of aphyric porous rocks and vitreous rocks.
AD 12	Rock	2,916	2,817	Tuff	Rock fragments. Coarse, fragile.
AD 12	Rock	2,916	2,817	Reefal limestone	Rock fragments. Coral structure confirmed.
LC 01	Rock	3,748		Mudstone	Solidified brown ooze surface.

Appendix Table 2 (3-1) Rock Samples from MC13 Area

Sample number	Rock type	Water depth (m) On bottom	Water depth (m) Off bottom	Substrate	Description
98 AD 03	Congromeratic crust substrate	1,735	1,669	Limestones(micrite)	Micrite. White. hard. bedded. Contain micronodules.
AD 03	Congromeratic crust substrate	1,735	1,669	Foraminiferal limestone	Contain micronodules. Cracks developed. phosphatized along cracks.
AD 03	Congromeratic crust substrate	1,735	1,669	Phosphorite	Pale brown. Phosphatized limestone. compact. hard.
AD 03	Nodule nucleus.	1,735	1,669	Phosphorite	Subrounded pebbles. Grayish brown. compact. hard.
AD 03	Nodule nucleus.	1,735	1,669	Mudstone	Subrounded pebbles. reddish brown. very fine grained.
AD 03	Nodule nucleus.	1,735	1,669	Phosphorite	Flat pebbles. grayish brown. compact. hard.
AD 03	Rock	1,735	1,669	Foraminiferal limestone	Contain flat basalt pebbles. Relatively hard.
AD 12	Congromeratic crust substrate	1,960	1,885	Chert	Hard, brown, translucent. Cleavages inside. Cracks with 3~4cm interval. but closely stuck.
AD 12	Congromeratic crust substrate	1,960	1,885	Mudstone	Brown mudstone solidified around 1~2.5cm nodules. Fine grained compact.
AD 12	Congromeratic crust substrate	1,960	1,885	Foraminiferal limestone	Brown clay mixed. Spongy. fragile.
AD 12	Congromeratic crust substrate	1,960	1,885	Calcareous conglomerate	Pebbles are nodules with basalt nuclei.
AD 12	Congromeratic crust substrate	1,960	1,885	Foraminiferal limestone	Phosphatized. pink. Hard. Contain micronodules.
AD 12	Congromeratic crust substrate	1,960	1,885	Phosphorite	Subrounded pebbles. White. hard.
AD 12	Congromeratic crust substrate	1,960	1,885	Calcareous conglomerate	Contain about 20mm angular~subangular basalt pebbles. Matrix phosphatized.
AD 12	Nodule nucleus.	1,960	1,885	Basalt	Aphyric, vitreous.
AD 12	Nodule nucleus.	1,960	1,885	Phosphorite	Grayish white, hard.
AD 12	Nodule nucleus.	1,960	1,885	Foraminiferal limestone	Milky white. Phosphatized. hard.
AD 12	Rock	1,960	1,885	Mudstone	Brown. very fine grained. massive. Some parts white by calcite mixture. surface coated.
AD 12	Rock	1,960	1,885	Basalt	Aphyric. vitreous. Surface gradation~coated.
AD 12	Rock	1,960	1,885	Tuff	Fine grained. compact. Surface gradation~coated.
AD 12	Rock	1,960	1,885	Foraminiferal limestone	Coarse grained. no pebbles. Surface gradation~coated.
AD 14	Nodule nucleus.	2,149	2,052	Basalt	Aphyric. vitreous. Subangular~subrounded pebbles.
AD 14	Nodule nucleus.	2,149	2,052	Foraminiferal limestone	Basalt granules. Contain small crust fragments.
AD 14	Nodule nucleus.	2,149	2,052	Tuff	Fine grained. Contain micronodules. Subrounded~flat pebbles.
AD 14	Nodule nucleus.	2,149	2,052	Phosphorite	Gray~pink. Hard. subangular~flat pebbles.
AD 14	Nodule nucleus.	2,149	2,052	Mudstone	Brown. Very fine grained. Contain micronodules. Subangular pebbles.
AD 07	Congromeratic crust substrate	2,208	1,834	Limestones(micrite)	Milky white, compact, hard. Minute lengthwise, cracks developed. Many trace fossils.
AD 07	Congromeratic crust substrate	2,208	1,834	Mudstone	Brown mudstone solidified around 3~6cm nodules. Fine grained, compact.
AD 07	Congromeratic crust substrate	2,208	1,834	Basalt (Subrounded foraminiferal limestone pebbles)	Fine-grained basalt with 0.5~10mm phenocrysts. Contain olivine and azurite.
AD 07	Nodule nucleus.	2,208	1,834	Basalt	Aphyric, vitreous.
AD 07	Congromeratic crust substrate	2,208	1,834	Limestones(micrite)	White, hard. Stratified structure.
AD 07	Rock	2,208	1,834	Basalt	Subrounded~flat pebbles. Aphyric, vitreous. Surface gradation.
AD 07	Rock	2,208	1,834	Calcareous conglomerate	Coarse grained. Angular~subangular basalt, tuff, phosphorite pebbles.
AD 07	Rock	2,208	1,834	Tuff	Fine grained, compact, but fragile. Surface stain.
AD 04	Rock	2,283	2,019	Basalt	Fine grained, grayish black. Fresh. Phenocrysts small. Augite・quartz clearly observed.
AD 04	Rock	2,283	2,019	Mudstone	Pale reddish brown. very fine grained. massive. Contain small crust fragments. Foraminiferal limestone stuck on upper surface.
AD 06	Crust substrate	2,331	2,101	Calcareous conglomerate	Upper part weathered rounded basalt pebbles phosphatized, lower part contains small angular basalt pebbles.
AD 06	Congromeratic crust substrate	2,331	2,101	Calcareous conglomerate	Calcite cements angular~subangular basalt and subrounded tuff pebbles. Matrix fragile.
AD 06	Congromeratic crust substrate	2,331	2,101	Calcareous conglomerate	Calcite cements rounded basalt and flat phosphorite pebbles. Matrix fragile.
AD 06	Congromeratic crust substrate	2,331	2,101	basalt	aphyric, vitreous. Cracks developed. Cracks filled by calcite. Breccia structure.
AD 06	Congromeratic crust substrate	2,331	2,101	Basalt	Phyric, vitreous. Cracks developed. Cracks filled by calcite. Strongly weathered.
AD 06	Congromeratic crust substrate	2,331	2,101	Basalt	Aphyric, vitreous. Strongly weathered. Limestone attached on sides.
AD 06	Rock	2,331	2,101	Basalt	Fine grained, phyric, minute vesicles filled by nephrite.
AD 06	Rock	2,331	2,101	Tuff breccia	Pumiceous, tuff with onion type weathering, basalt granules (xenoliths) and phosphorite contained.
AD 02	Crust substrate	2,384	2,118	Mudstone	Pale brown, very fine grained, clear bedding, micronodules on bedding planes.
AD 02	Congromeratic crust substrate	2,384	2,118	Mudstone	Reddish brown mudstone. Very fine grained. Homogeneous and massive. Contain micronodules.
AD 02	Nodule nucleus.	2,384	2,118	Basalt	Flat pebbles. Porous, phyric.
AD 02	Nodule nucleus.	2,384	2,118	Basalt	Subrounded pebbles. Porous, phyric.
AD 02	Nodule nucleus.	2,384	2,118	Foraminiferal limestone	Subrounded pebbles. Many pipe trace fossils and vesicles. Coarse soft.
AD 02	Nodule nucleus.	2,384	2,118	Mudstone	Subrounded pebbles. Very fine grained, dark brown. Contain micronodules. Trace fossils.
AD 02	Rock	2,384	2,118	Mudstone	Pale reddish brown, very fine grained. Massive. Contain micronodules. Subrounded 1cm basalt pebbles mixed.
AD 02	Rock	2,384	2,118	Basalt	Minute vesicles. Phyric. Matrix fine grained, rock forming minerals clearly observed.
AD 02	Rock	2,384	2,118	Tuff	Pumiceous, contain onion-type weathered tuff. Vesicles filled by calcite.
AD 02	Rock	2,384	2,118	Foraminiferal limestone	Lower part nodule-containing subrounded tuff. Upper part contains angular basalt pebbles. Partly phosphatized.
AD 13	Crust substrate	2,443	2,328	Basalt	Aphyric, fine-grained basalt. Contain minute grains with metallic luster.
AD 13	Crust substrate	2,443	2,328	Basalt	Aphyric, porous basalt. Minute vesicles. filled by nephrite.

Appendix Table 2 (3-2) Rock Samples from MC13 Area

Sample number	Rock type	Water depth (m) On bottom	Water depth (m) Off bottom	Substrate	Description
98 AD 08	Congromeratic crust substrate	2,484	2,339	Basalt	Porous, 5~100mm phenocrysts. Cracks developed, weathered.
AD 08	Congromeratic crust substrate	2,484	2,339	Foraminiferal limestone	Subrounded pebbles. Pipe trace fossils and vesicles abundant, coarse, soft
AD 08	Rock	2,484	2,339	Basalt	Flat pebbles, porous. 5~10mm phenocrysts. Surface coated.
AD 08	Rock	2,484	2,339	Calcareous conglomerate	White, coarse, soft. Contain angular basalt pebbles. Surface merely stained.
AD 05	Rock	2,783	2,458	Basalt	Grayish black, fresh. Aphyric, vitreous. Minute augite occur throughout.
AD 05	Rock	2,783	2,458	Mudston	Pale reddish brown, very fine grained, homogeneous, massive. Hard.
AD 11	Rock	2,959	2,535	Basalt	Aphyric, fine grained. Black spherical mineral smaller than o.2mm observed. Surface merely stained.
AD 11	Rock	2,959	2,535	Basalt	Very fine grained. Lightgray irregular 2~ 7mm phenocrysts. Surface gradation.
AD 11	Rock	2,959	2,535	Tuff	Contain green tuff pebbles (xenoliths). Matrix pumiceous, surface stained~gradation.
AD 11	Rock	2,959	2,535	Tuffaceou mudstone	Subrounded pebbles. Fine grained, compact, homogeneous, but light, fragile. Surface less than stain.
AD 11	Rock	2,959	2,535	Chert	Hard. Opaque, but vitreous luster. Calcite attached on surface.
LC 01	Nodule nucleus.	3,422		Phosphorite	Gray. Hard, flat pebbles.
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	2,087	Basalt	Phyric, porous, phenocrysts not clear.
AD 06	Substrate rock of Nodule	2,274	2,087	Basalt	Phyric, porous, phenocrysts not clear.
AD 06	Rock	2,274	2,087	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 2 (4) Rock Samples from MS13 Area

Sample number	Rock type	Water depth (m) On bottom	Water depth (m) Off bottom	Substrate	Description
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	2,087	Basalt	Phyric, porous, phenocrysts not clear.
AD 06	Substrate rock of Nodule	2,274	2,087	Basalt	Phyric, porous, phenocrysts not clear.
AD 06	Rock	2,274	2,087	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: SMC11AD0T01				
Rock: Altered pyroxene olivine basalt				
Description(unaided eyes): Reddish brown. Phyric texture.				
Description (microscopic) :				
Rock texture: Phyric texture. Phenocryst plagioclase show strong flow structure. Vitreous matrix (devitrified).				
Phenocryst minerals description:				
Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Subhedral, Prismatic	0.1×0.5mm	～40%	Crystals well-oriented, show marked flow structure.
Clinopyroxene	Subhedral, Granular	0.3×0.5mm	5～10%	Paragenetic with opaque minerals, unaltered.
Olivine	Short prismatic	0.4×0.3mm	～5%	Altered (iddingsite), pseudomorph.
Matrix description: Vitreous matrix, but devitrification also observed. Smectite formed.				
Mineral	Shape	Grain diameter	Content	Description
Volcanic glass.	Irregular.		～40%	Reddish brown, partly devitrified.
Alteration: Alteration medium. Volcanic glass of matrix and phenocryst olivine altered to smectite and iddingsite respectively.				
Altered mineral description:				
Mineral	Shape	Grain diameter	Content	Description
Smectite	Patch		～10%	Patches of volcanic glass, form as product of devitrification.
Iddingsite	Olivine Pseudomorph			Pseudomorphic alteration of olivine.

Sample: SMC11AD06T01				
Rock: Vitreous porous basalt.				
Description(unaided eyes): Brown, porous basalt with blackish brown crust on surface. Spherulitic～amygdaloidal phenocrysts.				
Description (microscopic) :				
Rock texture: Phyric, porous, vitreous matrix. Matrix plagioclase show weak flow structure. Smectite fills voids with spherulitic～amygdaloidal texture.				
Phenocryst minerals description:				
Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Prismatic Subhedral	Max 5.0×7.0mm	～20%	Twinned, unaltered, weak zonal structure, vermicular corroded texture.
Olivine	Subhedral, (Pseudomorph)	0.4×0.5mm	～2%	Pseudomorph (iddingsite)
Matrix description: Vitreous, very fine acicular plagioclase (weak flow structure) observed locally.				
Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Acicular	0.01×0.1mm	～1%	Occur with weak flow structure in the vitreous matrix.
Volcanic glass	Irregular		～40%	Weakly devitrified.
Silica minerals	Fine granular	0.01mm	～10%	Pools in matrix.
Alteration: Alteration generally weak. Mostly devitrification of matrix and iddingsitization of olivine (pseudomorph). Plagioclase phenocrysts corroded vermicularly.				
Altered mineral description:				
Mineral	Shape	Grain diameter	Content	Description
Iddingsait	Splinter Aggregates～Irregular acicular.	～0.01mm		Pseudomorphic alteration of olivine.
Smectite	Granular.	～1.2mm	～20%	Void filling, Hollow center.

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

Sample: SMC12AD06T02

Rock: Pisolitic pelitic rock~sandstone (contain microfossils)

Description(unaided eyes): Reddish brown. Pisolitic~subrounded pebbles, fragile.

Description (microscopic) :

Rock texture: Oolitic~pisolitic, partly colloform.

Clastics description: Although not clear clastic, polymictic clastic material, microfossils (radiolaria etc.), and authigenic prismatic crystals are observed.

Mineral	Shape	Grain diameter	Content	Description
Microfossil			~5%	Radiolaria, foraminifera (?)
Clastics.	Subrounded Pebble	~1.5mm	~30%	Original material unknown.
Unidentified mineral	Prismatic, radial	0.1 × 0.02mm	~10%	Authgenic, zeolite a possibility.

Matrix description: Smectite, carbonate minerals formed in matrix.

Mineral	Shape	Grain diameter	Content	Description
Carbonate	Granular~void filling.	~0.02mm	~5%	Formed in matrix.
Hematite	Minute Aggregates.	~0.1mm		Fragmented parts hematitized.
Volcanic glass	Irregular		~40%	Partly smectitized.

Alteration: Alteration intermediate. Formation of smectite-like mineral and authigenic mineral (zeolite ?).

Altered mineral description:

Mineral	Shape	Grain diameter	Content	Description
Smectite	Irregular	~0.01mm	~10%	Minute amount formed in volcanic glass. Partly vein.
Authigenic Unidentified mineral(zeolite ?)	Prismatic, radial,	0.1 × 0.02mm	~10%	Authigenic mineral (?), possibility of zeolite (same as phenocryst).

Sample: SMC12AD13T02

Rock: Porous aphyric basalt.

Description(unaided eyes): Greenish-brown gray, porous, spherulitic~amygdaloidal texture developed. Spherulites are white~brown material filling voids.

Description (microscopic) :

Rock texture: Cryptocrystalline. Calcite-brown carbonate minerals fill voids and show spherulitic~amygdaloidal texture.

Phenocryst minerals description: Aphyric

Mineral	Shape	Grain diameter	Content	Description

Matrix description: Cryptocrystalline, vermicular plagioclase and devitrified vitreous matrix.

Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Vermicular	0.01 × 0.04mm	~35%	Vermicular, flow structure not clear.
Volcanic glass	Irregular		~20%	Devitrified.

Alteration: Alteration not significant except devitrification of matrix. Alteration minor.

Altered mineral description:

Mineral	Shape	Grain diameter	Content	Description
Calcite.	Granular, radial	0.7 × 1.2mm	~40%	Often fills voids. Locally accompanied by brown carbonate minerals(zonal structure).
Brown carbonate	Granular, radial	0.3~0.5mm	~5%	Closely associated with calcite, early spherulite.

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

Sample: SMC13AD02T01				
Rock: Vitreous microphyric altered basalt.				
Description(unaided eyes): Yellowish brown basalt. Clayey, fragile, microphyric, contain vein～pipe white clayey parts.				
Description (microscopic) :				
Rock texture: Microphyric texture, vitreous matrix, crystallites notable.				
Phenocryst minerals description:				
Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Subhedral, Prismatic	0.4×1.8mm	～5%	Altered pseudomorph (clay minerals formed).
Clinopyroxene	Subhedral, sort Prismatic	0.5×0.9mm	～1%	Altered pseudomorph (smectite formed)
Matrix description:Crystallite minerals formed in the vitreous matrix.				
Mineral	Shape	Grain diameter	Content	Description
Crystallite		Max 0.3～0.4mm	～20%	Rapid growth (quench), mineral unknown
Hematite	Stain		～10%	Matrix partly red.
Volcanic glass	Irregular		～60%	
Alteration: Alteration weak. Weak devitrification observed in volcanic glass matrix.				
Altered mineral description:				
Mineral	Shape	Grain diameter	Content	Description
Smectite	Pseudomorph		～10%	Clinopyroxene (?), plagioclase (?), pseudomorph. Product of vitreous matrix devitrification.

Sample: SMC13AD04T01				
Rock: Dolerite				
Description(unaided eyes): Yellowish green brown. Fine grained, compact, aphyric. Weakly altered.				
Description (microscopic) :				
Rock texture: Holocrystalline, coarse grained, ophitic texture characteristic of dolerite.				
Phenocript minerals description:				
Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Subhedral, Prismatic.	1×0.1mm	～40%	Twinned, fresh, partly skeleton crystal.
Clinopyroxene	Subhedral, sort Prismatic.	Max: 1×2mm	～40%	Fresh, ophitic texture with plagioclase.
Matrix description: Matrix microholocrystalline. Vermicular plagioclase, devitrified glass observed.				
Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Prismatic.	0.2×0.02mm	～10%	Vermicular in matrix.
Volcanic glass			～5%	Devitrified, smectite-like clay mineral formed.
Alteration: Alteration weak. Devitrification of volcanic glass observed.				
Altered mineral description:				
Mineral	Shape	Grain diameter	Content	Description
Smectite	Platy～irregular	0.01mm	～5%	Devitrified product of volcanic glass.

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

Sample: SMC13AD08T01

Rock: Pyroxene basalt.

Description(unaided eyes): Green brown, porous, weakly altered. Phyric with fine plagioclase phenocrysts (~8mm).

Description (microscopic) :

Rock texture: Macrophyric texture, amygdaloidal texture. Phenocryst・matrix plagioclase show weak flow structure.

Phenocript minerals description:

Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Subhedral, Prismatic.	Max 0.8×1.2mm	20~30%	Coarse grained, large phenocrysts, medium-grained phenocrysts. Magma inclusions observed.
Clinopyroxene (amygdaloidal)	Subhedral, Granular, Spheroidal~Ellipsoidal.	0.2~0.4mm	~10%	Granular aggregates, closely attached to plagioclase, smectite fills interstices (incrustations~colloform).

Matrix description:

Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Subhedral, prismatic.	0.04~0.3mm	10~20%	Vermicular in matrix.
Opaque minerals.	Subhedral, Granular.		~5%	Scattered in matrix.
Volcanic glass			~20%	Void filling in matrix. Devitrified.

Alteration: Alteration generally weak. Veins, alteration of volcanic glass. Partly plagioclase altered.

Altered mineral description: The description is for matrix.

Mineral	Shape	Grain diameter	Content	Description
Smectite	Splintery.	0.05~0.1mm	~5%	Occur as fillings in amygdaloids, and veins.
Quartz	Very fine grained. Mosaic.	0.01mm	~1%	Patch-form alteration product of plagioclase.

Sample: SMC13AD13T01

Rock: Dolerite

Description(unaided eyes): Yellowish green brown, fine grained, weakly altered. Microdorerite (?).

Description (microscopic) :

Rock texture: Holocrystalline, semi-equigranular. Ophitic texture characteristic of dolerite.

Phenocript minerals description:

Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Subhedral, Prismatic	0.04×0.2mm	~40%	Prismatic, flow structure not observed.
Clinopyroxene	Subhedral, Granular.	0.1~0.3mm	~40%	Granular, ophitic texture.
Opaque minerals.	Anhedral, Granular.	0.1~0.2mm	~5%	Scattered throughout

Matrix description: Smectite (mixed layer with chlorite ?) fills the crystal grain interstices of the matrix.

Mineral	Shape	Grain diameter	Content	Description

Alteration: Alteration generally weak. Smectite-like mineral observed as a product of matrix volcanic glass devitrification.

Altered mineral description:

Mineral	Shape	Grain diameter	Content	Description
Smectite	Spherulitic, Corona form.	0.02~0.05mm	~5%	Altered volcanic glass (devitrification product ?).
	Feather from Splintery, Radial.	0.1~0.01mm	~10%	Occurs filling the interstices of crystal grains (possibility of volcanic glass alteration product). Possibility of mix-layer with chlorite.

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.
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,	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.
	Granular.	0.4～0.6mm	～5%	

Appendix Table 3(6) Description of microscopic observation for rock thin section

Sample: SMC02AD11T01

Rock: Basalt

Description(unaided eyes): Yellowish green brown, relatively fresh, unaltered. Microphyric, black･white speckled, plagioclase phenocrysts observed.

Description (microscopic) :

Rock texture: Microphyric texture (partly splinter aggregate texture). Plagioclase in both phenocrysts and matrix shows flow structure.

Phenocript minerals description:

Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Subhedral, Prismatic～Granular	Max 0.5×1.2mm Generally 0.05×0.02mm	20～30%	Many medium-grained prismatic plagioclase have skeleton crystal generally with flow structure. Few altered.

Matrix description: Vitreous matrix. Clinopyroxene, plagioclase, opaque minerals observed.

Mineral	Shape	Grain diameter	Content	Description
Plagioclase	Subhedral, Prismatic.	0.1×0.02mm	～10%	Flow structure. Acicular～skeleton crystals, unaltered.
Clinopyroxene	Subhedral, Sort Prismatic～Granular.	0.02～0.05mm	～10%	Scattered in matrix. Alteration not observed.
Volcanic glass	Irregular		～40%	Partly altered to smectite.

Alteration: Alteration generally weak. Smectite formed by devitrification of volcanic glass.

Altered mineral description:

Mineral	Shape	Grain diameter	Content	Description
Smectite	Platy～splintery	0.1～0.02mm	～10%	Inferred to be devitrification product of volcanic glass in matrix.

Sample: SMC02AD11T02

Rock: Mudstone～siltstone (contain foraminifera).

Description(unaided eyes): Yellowish green brown. Clayey, microphyrite, fragile.

Description (microscopic) :

Rock texture: Fossiliferous mudstone～siltsone.

Clasts description: Few clastic material, but fossiliferaous mudstone～siltstone (pelagic sedimentary rock). Clastic material are silica minerals, volcanic glass, basaltic volcanic rocks.

Mineral	Shape	Grain diameter	Content	Description
Silica minerals.	Anhedral	～0.2mm	～30%	
Volcanic glass.	Irregular		～10%	

Matrix description: Matrix consists of opaque minerals, smectite altered from volcanic glass.

Mineral	Shape	Grain diameter	Content	Description
Opaque minerals.		～0.05mm	～10%	

Alteration: Alteration medium. Smectite occurs throughout the matrix.

Altered mineral description: Volcanic glass and authigenic minerals of matrix altered to smectite, authigenic minerals partly remain.

Mineral	Shape	Grain diameter	Content	Description
Smectite	Splintery～Flat.	0.01mm	～50%	Formed by alteration of matrix and pyroclastic material (volcanic glass etc.) and also authigenically.

Appendix Table 4 Results of FDC survey

Sea-mount	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
MC11	98SMC11FDC01	IS	May 30 03:03					2:15	2.1	111	2
		SP	May 30 03:51	7° 30.411´N	161° 20.766´E	1,829	summit of east part of seamount				
		EP	May 30 06:06	7° 31.231´N	161° 22.736´E	3,036	middle part of northeast flank				
		OD	May 30 07:06								
MC12	98SMS12FDC01	IS	Jun 17 21:54					2:42	2.4	182	2
		SP	Jun 17 22:21	9° 19.904´N	146° 05.274´E	1,179	summit of east part of seamount				
		EP	Jun 18 01:03	9° 21.581´N	146° 07.059´E	2,514	middle part of northeast flank				
		OD	Jun 18 01:53								
MC13	98SMS13FDC01	IS	Jun 24 21:53					3:02	2.2	182	2
		SP	Jun 24 22:27	10° 26.095´N	145° 00.227´E	1,651	summit of east part of seamount				
		EP	Jun 25 01:29	10° 27.343´N	145° 02.057´E	3,187	middle part of northeast flank				
		OD	Jun 25 02:28								
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 margin of seamount 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								
MC02	98SMS02FDC01	IS	Jun 29 04:41					1:38	1.0	182	1
		SP	Jun 29 05:42	9° 10.664´N	141° 32.916´E	3,290	north flank of seamount				
		EP	Jun 29 07:20	9° 10.682´N	141° 33.874´E	3,269	depression of skirt				
		OD	Jun 29 08:18								
	98SMS02FDC02	IS	Jun 29 21:59					1:15	0.9	117	1
		SP	Jun 29 22:53	9° 09.999´N	141° 33.060´E	3,176	north flank of seamount				
		EP	Jun 30 00:08	09° 10.700´N	141° 33.656´E	3,269	depression of skirt				
		OD	Jun 30 01:09								
	98SMS02FDC03	IS	Jun 30 01:53					0:45	0.4	56	1
		SP	Jun 30 02:51	9° 10.048´N	141° 31.030´E	3,094	north flank of seamount				
		EP	Jun 30 03:38	9° 10.397´N	141° 31.231´E	3,317	depression of skirt				
		OD	Jun 30 04:38								

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	max	min	substrate	condition of surface	analyzed part	Co %	Ni %	Cu %	Mn %	Fe %	Pb %	Zn %	Ti %	Mo %	V %	Si %	Al %	Ca %	P %
MC11-area																							
98SMC11AD03CM02	2110	B	fragment	35	40	35		botryoidal	bulk	0.687	0.452	0.016	25.00	18.18	0.11	0.07	1.18	0.056	0.060	2.38	0.48	2.29	0.31
98SMC11AD03CM03	2110	B1	-	13	16	11	-	-	outer	0.971	0.564	<0.001	25.63	18.37	0.17	0.08	1.22	0.036	0.053	2.52	0.46	2.54	0.32
98SMC11AD03CM04	2110	B2	-	11	15	9	-	-	inner	0.664	0.476	0.002	22.96	17.93	0.13	0.07	1.28	0.048	0.056	2.89	0.60	2.30	0.25
98SMC11AD03CM05	2110	B3	-	15	18	13	-	-	innermost	0.716	0.459	0.019	24.49	19.56	0.13	0.08	1.20	0.074	0.068	2.38	0.46	2.46	0.32
98SMC11AD05CM01	2377	A	fragment	25	40	20		granule	bulk	0.665	0.441	0.015	22.91	17.43	0.11	0.06	1.19	0.046	0.049	3.54	0.86	2.11	0.26
98SMC11AD06CM01	2607	A	crust	37	40	35	basalt	granule	bulk	0.485	0.396	0.085	22.61	15.86	0.11	0.07	1.12	0.037	0.060	3.92	0.97	2.05	0.17
98SMC11AD06CM02	2607	A1	-	5	7	4	-	-	outer	0.481	0.382	0.046	22.54	17.17	0.12	0.07	1.12	0.044	0.058	4.20	0.91	2.18	0.28
98SMC11AD06CM03	2607	A2	-	10	12	7	-	-	inner	0.453	0.400	0.100	21.96	19.52	0.10	0.08	1.10	0.052	0.060	3.71	0.97	2.14	0.35
MC12-area																							
98SMC12LC01CM01	3788	A	sediment	-	-	-	solidified mud	-	bulk	0.015	0.069	0.034	5.92	9.82	0.01	0.03	0.47	0.003	0.012	22.10	5.35	1.62	0.09
98SMC12AD03CM01	1903	A	cobble	100	150	-	limestone	botryoidal	bulk	0.267	0.287	<0.001	16.58	18.60	0.09	0.08	1.23	0.042	0.055	3.75	1.14	3.57	0.72
98SMC12AD05CM01	1218	A	cobble	30	50	-	limestone	botryoidal	bulk	0.578	0.335	<0.001	20.26	17.72	0.15	0.07	1.16	0.053	0.066	1.85	0.59	8.89	2.65
98SMC12AD06CM03	2474	B	crust	140	150	120	hyaloclastite	botryoidal	bulk	0.166	0.154	<0.001	14.26	26.54	0.08	0.10	2.05	0.030	0.073	7.19	2.10	1.76	0.35
98SMC12AD06CM04	2474	B1	-	-	-	-	-	-	outer	0.399	0.292	0.004	22.86	20.39	0.14	0.06	0.99	0.049	0.070	3.87	0.74	2.21	0.38
98SMC12AD06CM05	2474	B2	-	-	-	-	-	-	inner	0.204	0.143	<0.001	13.65	24.60	0.12	0.14	2.79	0.020	0.086	6.92	1.90	1.92	0.28
98SMC12AD06CM06	2474	B3	-	-	-	-	-	-	innermost(1)	0.162	0.134	<0.001	12.62	26.23	0.07	0.13	2.40	0.022	0.077	6.16	1.65	1.47	0.27
98SMC12AD06CM07	2474	B4	-	-	-	-	-	-	innermost(2)	0.069	0.172	0.088	11.65	26.85	0.04	0.09	1.01	0.026	0.066	8.61	2.99	1.41	0.36
98SMC12AD06CM08	2474	D	nodule	8	8	6	mudstone	granule	bulk	0.445	0.454	0.141	21.58	19.95	0.13	0.08	1.22	0.034	0.066	4.20	1.11	2.14	0.35
98SMC12AD07CM01	2159	A	fragment	60	65	30		smooth	bulk	0.272	0.209	<0.001	16.20	22.95	0.10	0.11	2.12	0.024	0.069	5.60	1.50	2.09	0.28
98SMC12AD08CM01	1736	A	crust	50	70	30	tuff	botryoidal	bulk	0.943	0.345	0.021	21.18	21.88	0.12	0.09	1.44	0.049	0.072	3.63	1.33	2.13	0.28
98SMC12AD08CM02	1736	A1	-	-	-	-	-	-	outer	1.936	0.398	0.017	23.82	18.01	0.15	0.07	1.33	0.043	0.054	3.16	1.13	2.62	0.44
98SMC12AD08CM03	1736	A2	-	-	-	-	-	-	inner(1)	0.688	0.280	<0.001	19.30	21.46	0.12	0.09	1.87	0.034	0.055	4.62	1.51	2.18	0.27
98SMC12AD08CM04	1736	A3	-	-	-	-	-	-	inner(2)	0.693	0.299	0.011	20.23	24.74	0.10	0.09	1.67	0.035	0.075	3.42	1.20	1.86	0.25
98SMC12AD09CM01	1106	A	cobble	20	40	15	reefal limestone	smooth	bulk	0.523	0.344	<0.001	23.70	16.57	0.16	0.07	1.06	0.058	0.076	1.67	0.52	4.88	0.89
98SMC12AD13CM01	2309	A	crust	3	5	1	limestone	botryoidal	bulk	0.359	0.316	0.007	20.40	19.00	0.11	0.05	0.74	0.038	0.055	4.97	1.05	3.80	0.65
98SMC12AD14CM01	2280	A	crust	45	65	20	basalt	botryoidal	bulk	0.399	0.285	<0.001	19.49	17.95	0.11	0.06	1.38	0.040	0.050	4.46	1.18	2.21	0.28
98SMC12AD14CM04	2289	C	crust	65	70	50		botryoidal	bulk	0.166	0.149	<0.001	14.58	25.21	0.08	0.09	1.95	0.025	0.061	6.66	1.92	1.81	0.28
MC13-area																							
98SMC13AD02CM02	2299	B	crust	15	25	12	mudstone	botryoidal	bulk	0.254	0.241	0.080	14.82	20.96	0.09	0.10	1.58	0.022	0.049	9.11	2.80	2.69	0.45
98SMC13AD03CM01	1750	A	cobble	90	120	5	phosphorite	botryoidal	bulk	0.294	0.244	<0.001	16.46	21.27	0.09	0.08	1.59	0.024	0.052	6.24	1.79	2.99	0.27
98SMC13AD03CM02	1750	A1	-	-	-	-	-	-	outer	0.557	0.417	<0.001	20.14	20.03	0.16	0.08	1.19	0.040	0.056	4.61	1.14	2.25	0.32
98SMC13AD03CM03	1750	A2	-	-	-	-	-	-	inner	0.393	0.276	<0.001	16.39	22.85	0.12	0.12	2.11	0.025	0.054	6.60	1.88	2.29	0.32
98SMC13AD03CM04	1750	A3	-	-	-	-	-	-	innermost	0.166	0.239	0.057	13.82	23.77	0.05	0.11	1.36	0.026	0.062	7.60	2.49	3.64	0.40
98SMC13AD03CM05	1750	A4	-	-	-	-	-	-	lower innermost	0.478	0.407	0.012	20.68	19.92	0.12	0.07	0.98	0.038	0.061	5.79	1.45	2.49	0.30
98SMC13AD03CM22	1750	F	nodule	20	40	20	phosphorite, mudstone	granule, botryoidal	bulk	0.475	0.439	0.042	20.18	18.76	0.11	0.08	1.08	0.041	0.054	5.63	1.85	2.18	0.34
98SMC13AD05CM01	2798	C	fragment	15	30	3		granule	bulk	0.054	0.057	<0.001	6.80	11.62	0.02	0.03	0.94	0.006	0.031	19.63	6.63	6.91	0.18
98SMC13AD06CM09	2347	C	cobble	50	105	-	limestone	granule	bulk	0.392	0.289	0.025	18.24	23.10	0.12	0.08	1.40	0.041	0.064	5.39	1.45	2.01	0.35
98SMC13AD06CM17	2347	E	crust	50	60	40	conglomerate	granule	bulk	0.493	0.358	0.026	21.23	19.22	0.14	0.07	0.96	0.052	0.069	3.99	0.81	2.38	0.26
98SMC13AD07CM01	2043	A	cobble	35	100	-	limestone	botryoidal	bulk	0.328	0.284	<0.001	16.87	18.82	0.11	0.09	1.42	0.031	0.051	5.88	1.53	2.07	0.24
98SMC13AD07CM02	2043	A1	-	-	-	-	-	-	outer	0.500	0.381	0.007	22.42	19.49	0.13	0.07	0.93	0.050	0.062	4.34	0.94	2.29	0.36
98SMC13AD07CM03	2043	A2	-	-	-	-	-	-	inner	0.237	0.202	<0.001	13.92	22.47	0.08	0.11	2.03	0.021	0.055	8.29	2.48	1.92	0.29
98SMC13AD08CM02	2499	F	cobble	10	15	-	conglomerate	granule	bulk	0.519	0.430	0.052	22.00	20.40	0.13	0.08	0.96	0.047	0.061	4.70	1.15	2.54	0.38
98SMC13AD12CM13	1975	K	nodule	12	15	-	basalt,phosphorite	granule	bulk	0.377	0.376	0.043	18.62	17.97	0.10	0.09	1.23	0.034	0.052	7.16	2.38	2.64	0.45
98SMC13AD12CM15	1975	M	cobble	100	140	-		granule	bulk	0.334	0.286	0.013	16.60	24.54	0.10	0.09	1.68	0.030	0.059	6.88	1.99	1.99	0.34
98SMC13AD13CM01	2458	A	crust	1.5	3	1	basalt	granule	bulk	0.445	0.368	<0.001	20.37	21.31	0.13	0.06	1.15	0.027	0.056	4.83	1.04	3.31	0.30
98SMC13AD14CM01	2163	A	nodule	3	6	2	limestone, basalt, mudstone, phosphorite	granule	bulk	0.305	0.406	0.031	21.20	19.51	0.11	0.07	0.73	0.051	0.062	5.72	1.36	2.54	0.33

sample	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
MC11-area																
98SMC11AD03CM02	0.276	325	907	53.2	234	46	11.40	41	7.7	47	9.6	30	4.34	25	4.09	1.38
98SMC11AD03CM03	0.188	302	801	50.9	224	45	11.30	44	7.9	50	10.6	32	4.94	29	4.60	1.41
98SMC11AD03CM04	0.343	324	959	52.8	231	45	11.20	39	7.9	47	9.6	30	4.47	26	4.29	1.28
98SMC11AD03CM05	0.307	365	1011	61.6	262	51	12.30	45	8.5	52	10.0	33	4.75	27	4.40	1.25
98SMC11AD05CM01	0.230	262	764	37.0	165	32	8.20	30	5.9	38	8.2	26	3.91	24	4.11	1.31
98SMC11AD06CM01	0.282	274	772	44.1	191	37	9.57	35	6.6	40	8.2	26	3.76	22	3.82	1.43
98SMC11AD06CM02	0.152	287	746	44.2	198	39	9.94	37	7.1	44	9.0	29	4.23	25	4.10	1.31
98SMC11AD06CM03	0.316	285	763	45.6	199	39	9.66	35	6.7	40	8.3	26	3.85	23	3.80	1.13
MC12-area																
98SMC12LC01CM01	0.019	40	53	9.0	40	9	2.22	9.1	1.6	9	1.8	5	0.72	4.1	0.61	0.60
98SMC12AD03CM01	0.209	259	462	44.5	194	37	9.59	36	6.5	38	7.5	22	3.24	19	2.98	0.89
98SMC12AD05CM01	0.407	309	758	49.2	219	43	10.60	37	7.5	45	9.1	27	4.05	23	3.77	1.14
98SMC12AD06CM03	0.177	310	548	53.6	237	48	12.20	45	8.3	50	9.7	29	4.25	25	3.82	0.54
98SMC12AD06CM04	0.113	348	758	55.8	258	50	12.70	49	9.6	57	12.0	36	5.53	32	5.12	1.12
98SMC12AD06CM05	0.122	326	732	59.6	258	54	13.60	48	9.1	53	9.9	29	4.27	25	3.68	0.56
98SMC12AD06CM06	0.236	309	357	54.1	236	46	11.90	48	8.3	49	9.5	28	4.08	24	3.66	0.48
98SMC12AD06CM07	0.254	206	198	33.8	155	31	7.97	34	5.6	34	6.8	21	3.02	18	2.93	0.43
98SMC12AD06CM08	0.206	265	699	45.4	203	42	10.40	38	7.2	42	8.2	24	3.65	22	3.36	1.08
98SMC12AD07CM01	0.316	350	623	61.3	271	55	14.00	52	9.6	57	11.0	33	4.87	28	4.47	0.71
98SMC12AD08CM01	0.673	318	708	47.5	210	41	10.30	35	7.0	41	8.1	25	3.70	22	3.63	0.97
98SMC12AD08CM02	0.588	281	936	40.0	180	34	8.80	30	6.0	36	7.6	23	3.39	20	3.46	1.32
98SMC12AD08CM03	0.550	332	741	50.5	223	43	10.80	39	7.5	44	9.0	28	4.12	24	4.00	0.90
98SMC12AD08CM04	0.730	319	568	49.7	215	42	10.40	37	6.9	41	8.1	25	3.53	22	3.59	0.82
98SMC12AD09CM01	0.295	318	905	51.0	225	45	10.90	37	7.6	43	8.5	26	3.90	22	3.55	1.43
98SMC12AD13CM01	0.159	302	621	54.4	245	51	12.80	47	8.5	50	9.8	29	4.22	26	4.06	1.07
98SMC12AD14CM01	0.197	283	707	49.2	231	51	12.70	45	8.6	49	10.0	30	4.90	29	4.66	1.09
98SMC12AD14CM04	0.295	276	494	46.0	207	42	10.80	40	7.4	45	8.8	26	3.90	23	3.62	0.58
MC13-area																
98SMC13AD02CM02	0.148	223	505	39.1	173	36	8.91	32	6.2	37	7.1	21	3.25	19	3.14	0.71
98SMC13AD03CM01	0.207	232	465	40.3	178	36	9.22	34	6.2	37	7.3	22	3.30	19	3.15	0.77
98SMC13AD03CM02	0.135	269	633	44.2	197	39	10.10	37	7.1	43	8.9	27	4.07	25	4.17	1.01
98SMC13AD03CM03	0.242	246	522	43.2	188	39	9.77	35	6.7	39	7.7	23	3.50	22	3.40	0.72
98SMC13AD03CM04	0.258	239	274	37.9	171	34	8.94	38	6.6	40	8.7	26	3.90	24	3.95	0.58
98SMC13AD03CM05	0.191	284	513	56.8	245	51	13.20	50	8.5	53	10.7	31	4.59	28	4.42	1.04
98SMC13AD03CM22	0.189	230	479	36.3	163	32	8.33	31	5.9	35	7.4	23	3.38	21	3.47	1.08
98SMC13AD05CM01	0.027	51	109	10.3	48	11	3.03	10	1.9	11	2.1	6	0.94	5.6	0.86	0.59
98SMC13AD06CM09	0.212	302	629	52.3	231	47	11.90	43	8.1	49	9.9	29	4.40	26	4.12	0.79
98SMC13AD06CM17	0.079	315	627	53.1	241	49	12.30	46	8.8	54	11.0	32	4.92	29	4.60	1.10
98SMC13AD07CM01	0.140	237	517	40.7	181	37	9.33	34	6.5	38	7.6	23	3.49	21	3.32	0.89
98SMC13AD07CM02	0.119	294	622	47.1	212	43	11.00	41	7.8	49	10.0	31	4.75	29	4.71	1.15
98SMC13AD07CM03	0.162	197	460	36.3	159	33	8.38	33	5.7	33	6.4	19	2.85	17	2.75	0.62
98SMC13AD08CM02	0.152	292	609	61.2	261	53	13.80	53	9.0	54	11.0	32	4.75	30	4.61	1.07
98SMC13AD12CM13	0.263	208	513	35.0	153	31	7.98	28	5.5	33	6.7	20	3.03	19	3.11	1.04
98SMC13AD12CM15	0.257	290	599	51.3	221	44	11.20	43	7.5	46	9.7	28	4.18	25	3.98	0.68
98SMC13AD13CM01	0.155	373	1042	76.7	335	69	17.20	59	11.0	62	12.0	35	5.04	30	4.62	0.96
98SMC13AD14CM01	0.186	264	584	52.7	224	46	12.00	45	7.7	47	9.7	28	4.10	26	3.97	1.09

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

sample	sampling depth(m)	code	type of crust	thickness (mm) ever	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	9.49	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	4.44	26	4.45	1.15
98SMS13AD06CM01	2289	A	crust	100	140	10	basalt	botryoidal	bulk	0.471	0.418	0.028	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	12.90	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	0.059	0.065	2.39	0.42	2.66	0.24	0.264	322	877	52.5	232	44	11.60	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	5	-	-	inner(3)	0.486	0.758	0.096	27.82	15.28	0.12	0.09	0.76	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	56.7	222	46	10.70	34	7.0	40	7.6	23	3.45	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	0.245	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	0.058	2.98	0.55	2.44	0.40	0.145	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	2.06	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	0.05	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	5.0	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	46.2	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

MC02		MC11		MC12		MC13		MS13	
Lat.	9°13.974'N	Lat.	7°29.996'N	Lat.	9°21.013'N	Lat.	19°28.053'N	Lat.	8°18.070'N
Long.	141°34.568'E	Long.	161°15.022'E	Long.	146°20.787'E	Long.	158°09.993'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 ($m \cdot s^{-1}$)	Water depth (m)	Sound velocity ($m \cdot s^{-1}$)
10	1,543.8	10	1,542.3	10	1,543.4	10	1,543.0	10	1,542.4
20	1,543.9	20	1,542.4	20	1,543.5	20	1,543.2	20	1,542.4
35	1,544.2	35	1,542.7	35	1,543.8	35	1,543.4	35	1,542.9
50	1,544.4	50	1,542.9	50	1,544.1	50	1,543.7	50	1,543.5
70	1,544.2	70	1,543.1	70	1,544.4	70	1,543.9	70	1,543.8
100	1,541.6	100	1,543.8	100	1,542.4	100	1,539.5	100	1,541.1
200	1,503.1	200	1,505.3	200	1,506.4	200	1,509.2	200	1,503.8
300	1,492.3	300	1,493.7	300	1,495.7	300	1,494.7	300	1,493.4
500	1,488.3	500	1,489.9	500	1,489.7	500	1,489.5	500	1,491.3
700	1,487.1	700	1,486.4	700	1,487.9	700	1,487.1	700	1,487.3
1,000	1,485.5	1,000	1,485.5	1,000	1,486.3	1,000	1,486.1	1,000	1,484.6
1,500	1,486.2	1,500	1,486.9	1,500	1,486.1	1,501	1,486.6	1,500	1,486.9
2,000	1,491.5	2,000	1,491.7	2,000	1,491.3	2,000	1,491.4	2,000	1,491.8
2,500	1,498.8	2,364	1,496.6	2,500	1,498.1	2,501	1,498.5	2,364	1,498.7
3,000	1,507.2	2,750	1,502.4	3,000	1,506.1	3,001	1,506.3	2,750	1,506.3
3,488	1,515.9	3,500	1,514.4	3,500	1,514.6	3,380	1,512.4	3,500	1,514.4
4,000	1,523.1	4,000	1,522.9	3,705	1,518.1	3,500	1,514.6	4,000	1,522.4
4,500	1,531.9	4,470	1,531.1	4,000	1,523.1	4,000	1,523.1	4,470	1,531.1
5,153	1,543.8	5,000	1,540.9	4,500	1,531.9	4,500	1,531.9	5,000	1,540.9
5,458	1,549.4	5,458	1,549.4	5,153	1,543.8	5,153	1,543.8	5,458	1,549.4
Ave.	6.0	Ave.	1,509.5	Ave.	1,507.4	Ave.	1,507.4	Ave.	1,509.9

Appendix Table 7 Weather and sea-state data

1.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
%	0.00	0.87	0.00	7.29	51.04	30.90	4.69	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00	4.17	100.00
June	0	2	6	45	265	181	44	22	6	1	1	1	1	0	0	0	1	24	600
%	0.00	0.33	1.00	7.50	44.17	30.17	7.33	3.67	1.00	0.17	0.17	0.17	0.17	0.00	0.00	0.00	0.17	4.00	100.00
July	0	0	0	0	0	14	90	72	15	1	0	0	0	0	0	0	0	0	192
%	0.00	0.00	0.00	0.00	0.00	7.29	46.88	37.50	7.81	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00

2.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
%	0.17	0.00	0.52	0.35	0.52	0.;7	2.08	4.34	14.41	23.09	22.05	17.01	8.51	5.03	1.39	0.35	0.00	0.00	0.00	0.00	0.00	0.00	100.00
June	1	0	5	4	10	18	54	76	95	120	106	84	23	2	0	0	1	0	1	0	0	0	600
%	0.17	0.00	0.83	0.67	1.67	3.00	9.00	12.67	15.83	20.00	17.67	14.00	3.83	0.33	0.00	0.00	0.17	0.00	0.17	0.00	0.00	0.00	100.00
July	0	0	0	0	0	5	33	80	50	22	2	0	0	0	0	0	0	0	0	0	0	0	192
%	0.00	0.00	0.00	0.00	0.00	2.60	17.19	41.67	26.04	11.46	1.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00

3.Monthly frequency distriction of weather in 1998

Weather	Fine	Cloudy	Rain	Not clear	Total	Light Rain
May	21	2	1		24	12
%	87.50	8.33	4.17	0.00	100.00	50.00
June	13	8	4		25	10
%	52.00	32.00	16.00	0.00	100.00	40.00
July	7	1	0		8	4
%	87.50	12.50	0.00	0.00	100.00	50.00

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