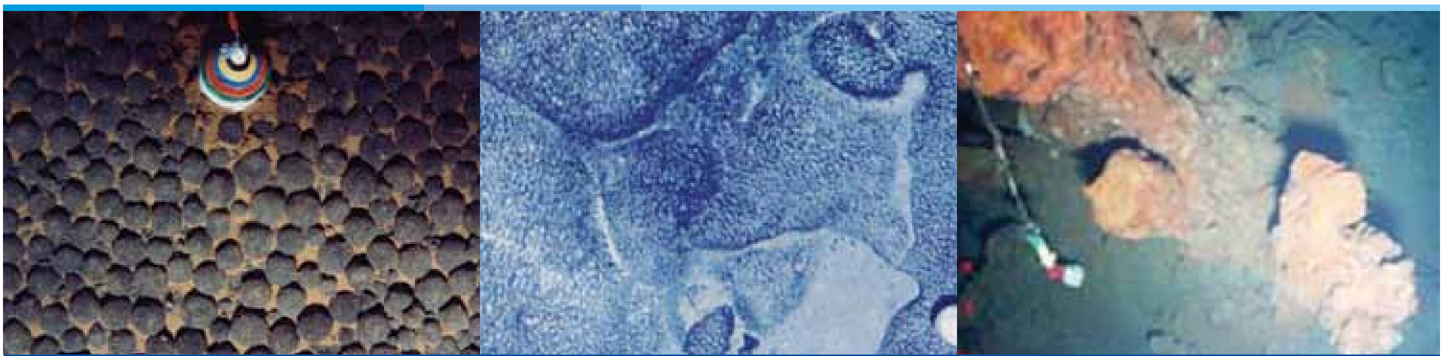
SPC
Secretariat of the Pacific Community
Applied Geoscience and Technology Division (SOPAC)

SPC-EU EDF10 Deep Sea Minerals (DSM) Project



Information Brochure 12
Republic of the Marshall Islands Deep-sea Minerals Potential

The Republic of the Marshall Islands (RMI) consists of atoll islands that occur largely in two seamount chains. The western chain is called Ralik Seamount Chain extending northwest-southeastward and includes the Kwajalein and the Bikini Atolls. The eastern chain is called the Ratak Seamount Chain extending north-northwest to south-southwestward and encompasses the Majuro Atoll. Bathymetry maps indicate that each island chain composes of atolls, seamounts and guyots (flat top seamounts). Early deep sea minerals investigations have been reported to have occurred within the Exclusive Economic Zone (EEZ) of the RMI but the only documented evidence sighted is from the 1989 Korea Ocean Research and Development Institute (KORDI)-United States Geological Survey (USGS) investigation and three Japan-SOPAC Cooperative Study surveys.

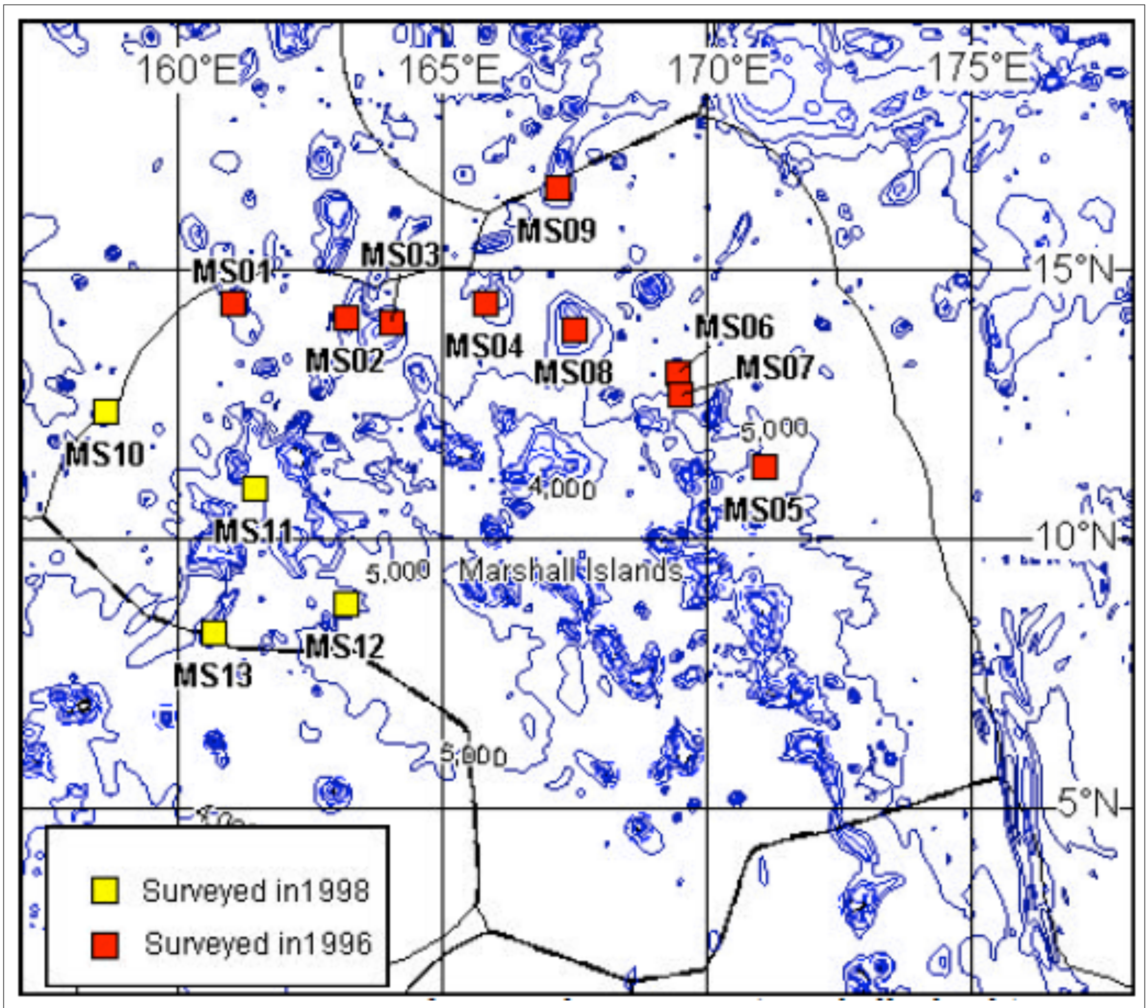


Figure 1. Location map of the 1996 and 1998 surveyed seamounts.

In 1989 KORDI-USGS successfully completed a cooperative cruise in the western EEZ of the RMI, investigating the Cobalt-rich Crusts (CRC) potential of nine seamounts.

Through the Japan-SOPAC partnership, offshore mineral investigations were conducted in 1996, 1998 and 2002.

The purpose of these surveys was to assess the potential of CRC resources in the EEZ of the RMI. Bathymetric maps of the RMI's EEZ and various charts were used to select the seamounts to be surveyed. Nine seamounts were surveyed in 1996 and another four were investigated in 1998 (Figure 1). Based on the 1996 and 1998 survey results, Seamounts MS01, MS11 and MS12 were selected and drilled in 2002, using the deep sea Boring Machine System (BMS). This enabled better understanding of the nature of the occurrence of CRC deposits on these three seamounts. Mineral resource estimates for the three seamounts were reviewed based on the new data collected in 2002.

This information brochure highlights the results of the three Japan-SOPAC surveys, and the information known about the CRC bearing potential of seamounts within the EEZ of the RMI.

Exploration History

Previous seabed mineral investigations that were conducted within the EEZ of the RMI are given in Table 1 below.

Table 1: Summary of previous offshore minerals exploration in the RMI.

Research Vessel and Year of Survey	Survey Area	Surveyed Commodity
RV Farnella (1989)	Nine seamounts in the western part of the RMI EEZ	Cobalt-rich Crusts
RV Hakurei Maru 2 (1996)	Nine seamounts in the northern part of the RMI EEZ	Cobalt-rich Crusts
RV Hakurei Maru 2 (1998)	Four seamounts in the western part of the RMI EEZ	Cobalt-rich Crusts
RV Hakurei Maru 2 (2002)	Three selected seamounts (i.e. MS01, MS11, and MS12) within the EEZ of the RMI	Cobalt-rich Crusts

Results

Summary of Survey Findings

1989 Survey

- About 90% of the rocks recovered are encrusted by ferromanganese oxides. The thickness of the crusts varies from a patina (<1 mm) to 150 mm.
- Ferromanganese crust surfaces are predominantly botryoidal with granular oxides common in recessed parts of the crusts.
- Thick crusts commonly exhibit several (up to 7) layers of various types, such as dense and massive, crudely laminated, and porous.
- Strong bottom current activity is indicated by fluted and polished botryoidal surfaces on the crusts, and by well-developed ripple marks in the foraminiferal sand that is observed on photographs taken at the seafloor.

1996 Survey

- The existence of CRC was confirmed in all the nine seamounts surveyed. The mode of occurrence of these crusts is similar in all seamounts, and it is inferred that the crusts occur in all seamounts with summits shallower than 2,000m in the survey area.

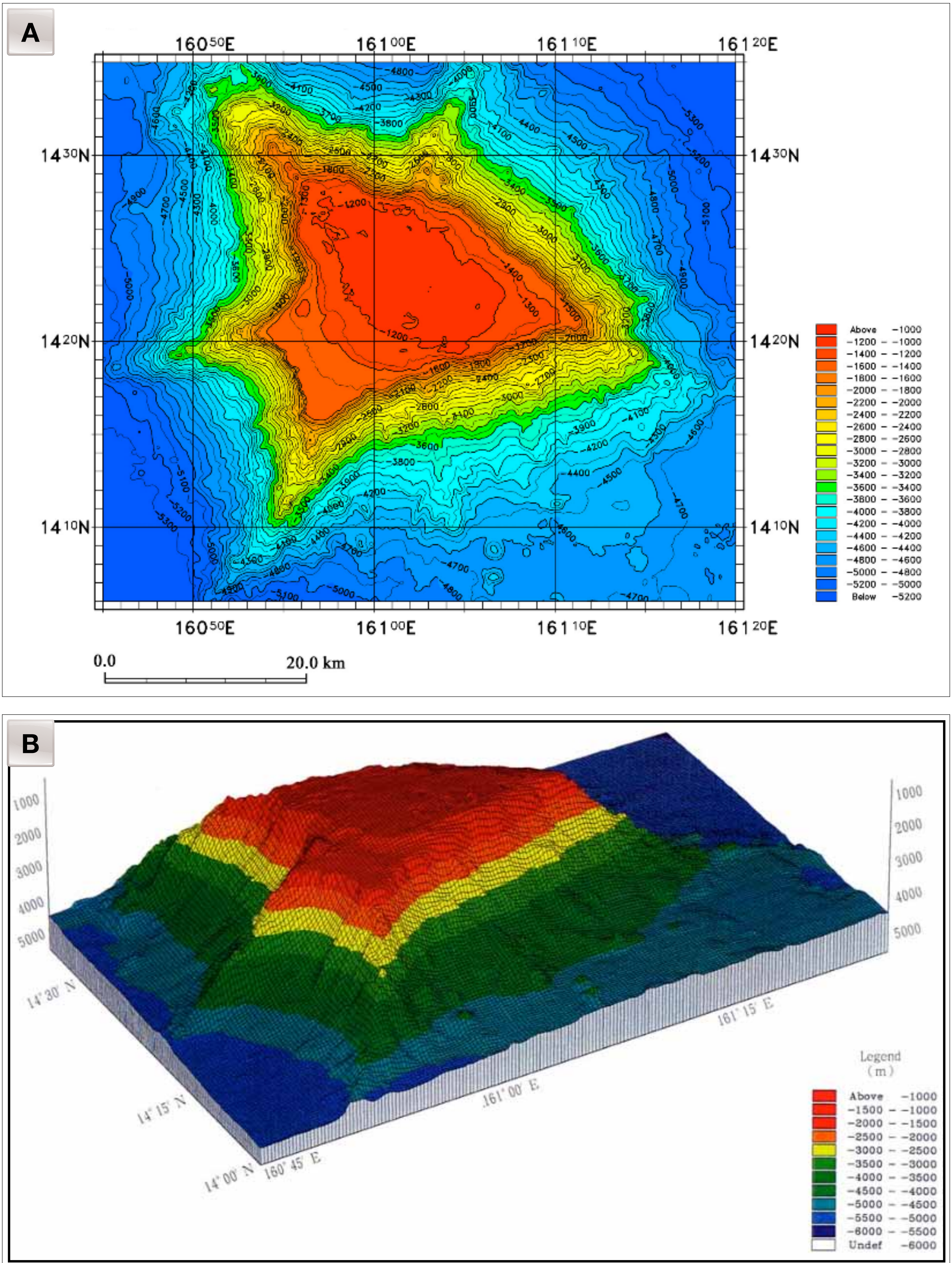


Figure 2. Bathymetry and topographic features of MS01; (A) Bathymetry map of MS01 Seamount, (B) 3-Dimensional view of MS01 Seamount showing various topographic features.

- Acoustic image maps prepared from Multi-narrow Beam Echo Sounder (MBES) acoustic pressure measurements are highly effective for understanding the areal extent and the distribution of CRC exposures on the seamount surface.
- Seamounts MS01 (Figure 2), MS02, MS04, MS05, and MS07 have relatively high degrees of CRC exposure. Cobalt content is high in the seamounts MS05 and MS07, and low in the seamounts MS01 and MS03. Platinum content is high in the seamount MS02, and somewhat low in the seamounts MS04 and MS06.
- A calculation of resource volume was carried out for the flat summit and the upper and middle slope of the seamounts, but excluding the lower slope, which had poor CRC exposures and thin crusts.
- The overall evaluation of the characteristics of CRC occurrence and the mineral resource suggest that seamounts MS01 and MS02 have significant potential among the nine seamounts while seamounts MS03, MS04, and MS08 have moderate potential.
- It has been proven that CRC occur widely from shallow summit down to 3,000 m water depth in all the surveyed seamounts. CRC are found to occur below seafloor sediments which presently cover the seafloor (Figure 3).

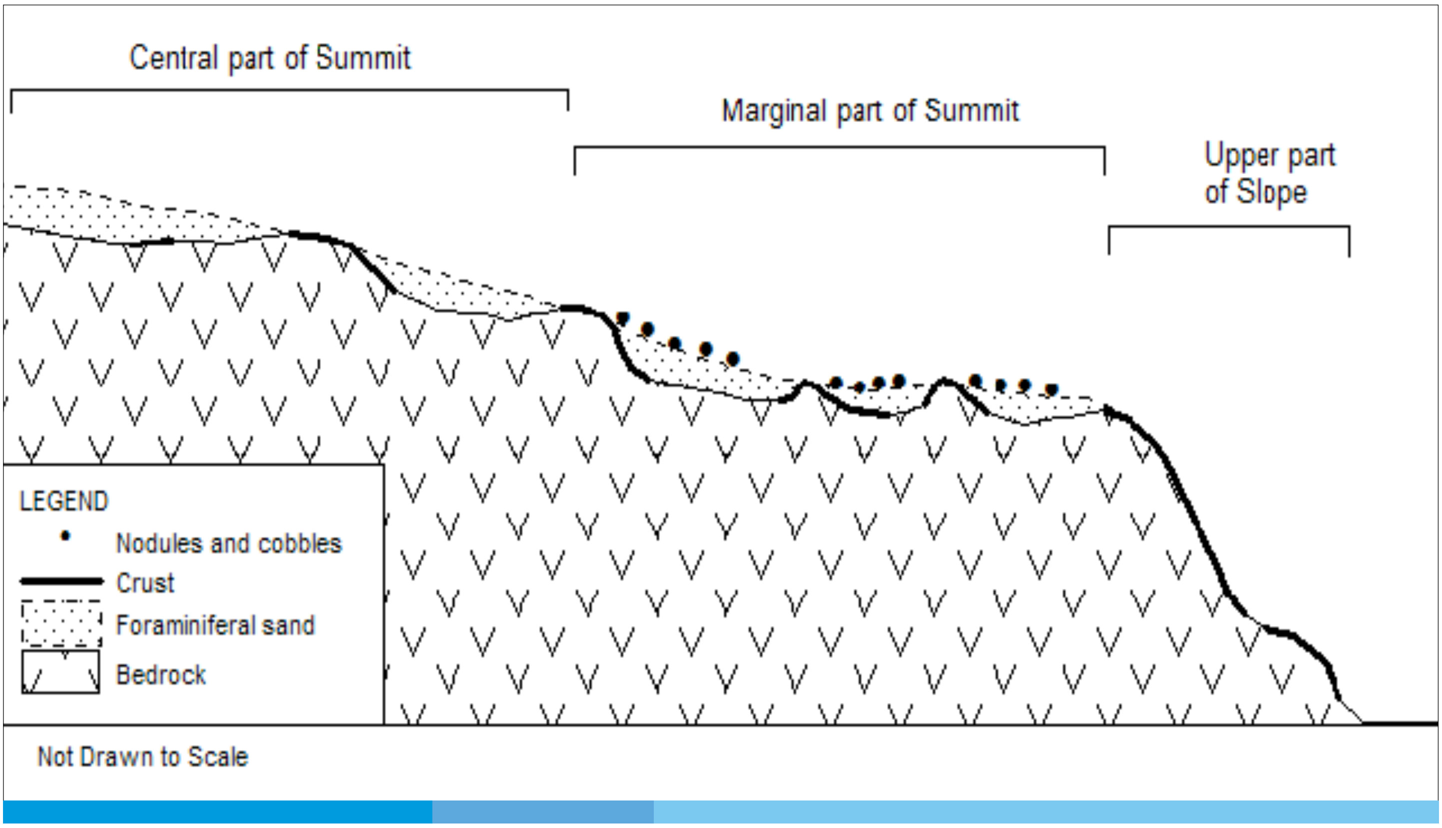


Figure 3. Schematic cross section of a cobalt-rich crust bearing seamount, illustrating the occurrence and distribution of crusts on various parts of the seamount surface.

1998 Survey

- Four seamounts were surveyed in 1998 (i.e. MS10 – MS13) and thick crusts are confirmed in all four areas. Three of these seamounts (MS10 – MS12) have many similarities in CRC occurrence including geology and metal content.
- Crusts and cobble crusts exceeding 100mm in thickness from the summit periphery to the upper slope occur in seamount MS10 – MS12. In the MS12 area (Figure 4), crust thickness of over 100mm was also confirmed to the middle slope.
- Compared to the seamounts surveyed in 1996, these seamounts tend to have thicker crusts but somewhat lower metal grade.

- The area surveyed in 1996 and 1998 comprises approximately the northwestern half of the EEZ of the Republic of Marshall Islands, and the distribution of seamounts and the conditions of CRC occurrence in the area are as follows:
  - The results of sampling and seafloor observation show that crusts thicker than 10cm occur at 1,000~3,500m water depth.
  - CRC predominantly occur as: crusts, cobble crusts, and nodules.
  - Crust thickness varies by areas, topography, and substrates.
  - The average thickness of the crusts by seamounts tends to be thicker to the west and the metal grade higher to the east.

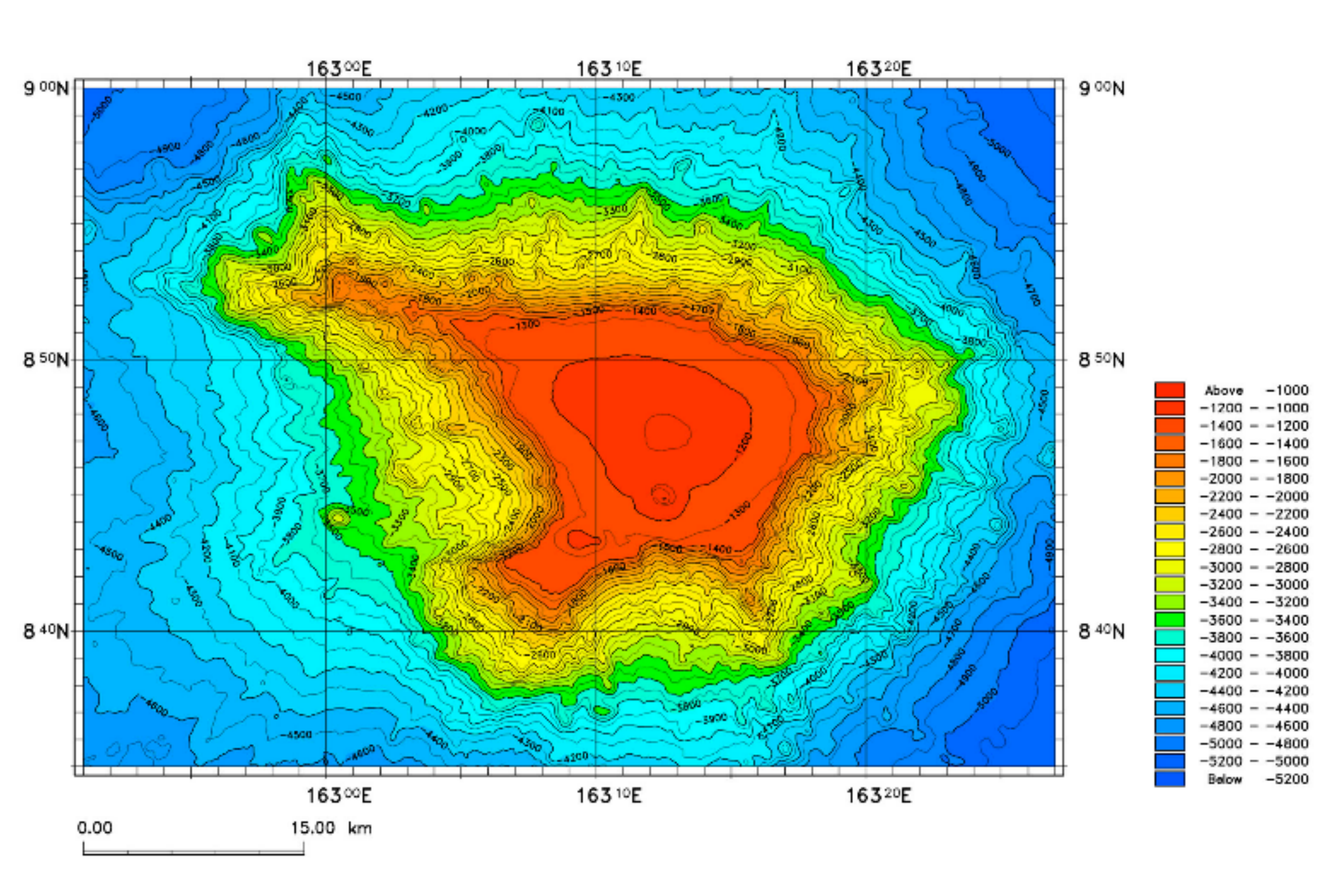


Figure 4. Bathymetry map of MS12 revealing the topographic features of the seamount.

- Due to the thick crusts in the western side and the high grade in the eastern side, the seamounts in the western part of the 1998 survey area have significant potential, followed by the seamounts continuing to the northern part of the Ralik Chain.
- A relation between the thickness and grade of CRC and the age of seamounts is recognized.
- The crusts are exposed widely on the upper slope of the seamount in the MS10 area, while thick crusts are concentrated in the periphery area of the summit.
- Crust exposure in MS11 is restricted to the summit periphery and parts of the slope and the exposure ratio is low. The size of the seamount is large and so as the total exposed area.
- In the MS12 seamount area, more than 20mm thick crusts are widely distributed from the summit periphery to the middle slope.
- The exposure ratio in the MS13 Seamount is generally low, and thick crusts are limited to the vicinity of the pinnacles that occur sporadically on the summit.

2002 Survey

- It is assumed that the average thickness of about 6cm (59mm) of CRC on seamount MS01 develops in the exposed area of the water depth of 1,200m to 1,600m from the margin of the summit to the summit.
- The average thickness of the cobalt crust at MS11 is 132mm compared to 38mm for the 1998 survey.
- The average thickness of the cobalt crust at MS12 is 70mm. In the survey result of 1998, the average thickness of cobalt crust was 33mm.
- The dark tone (highest acoustic reflection intensity) that develops around the shoulder of the summit indicates the occurrence of exposed rocks with high potential of CRC being attached to them.
- The 2002 drill locations on seamounts MS01, MS11 and MS12 and their respective drill cores are shown in Figures 5 to 10 below.

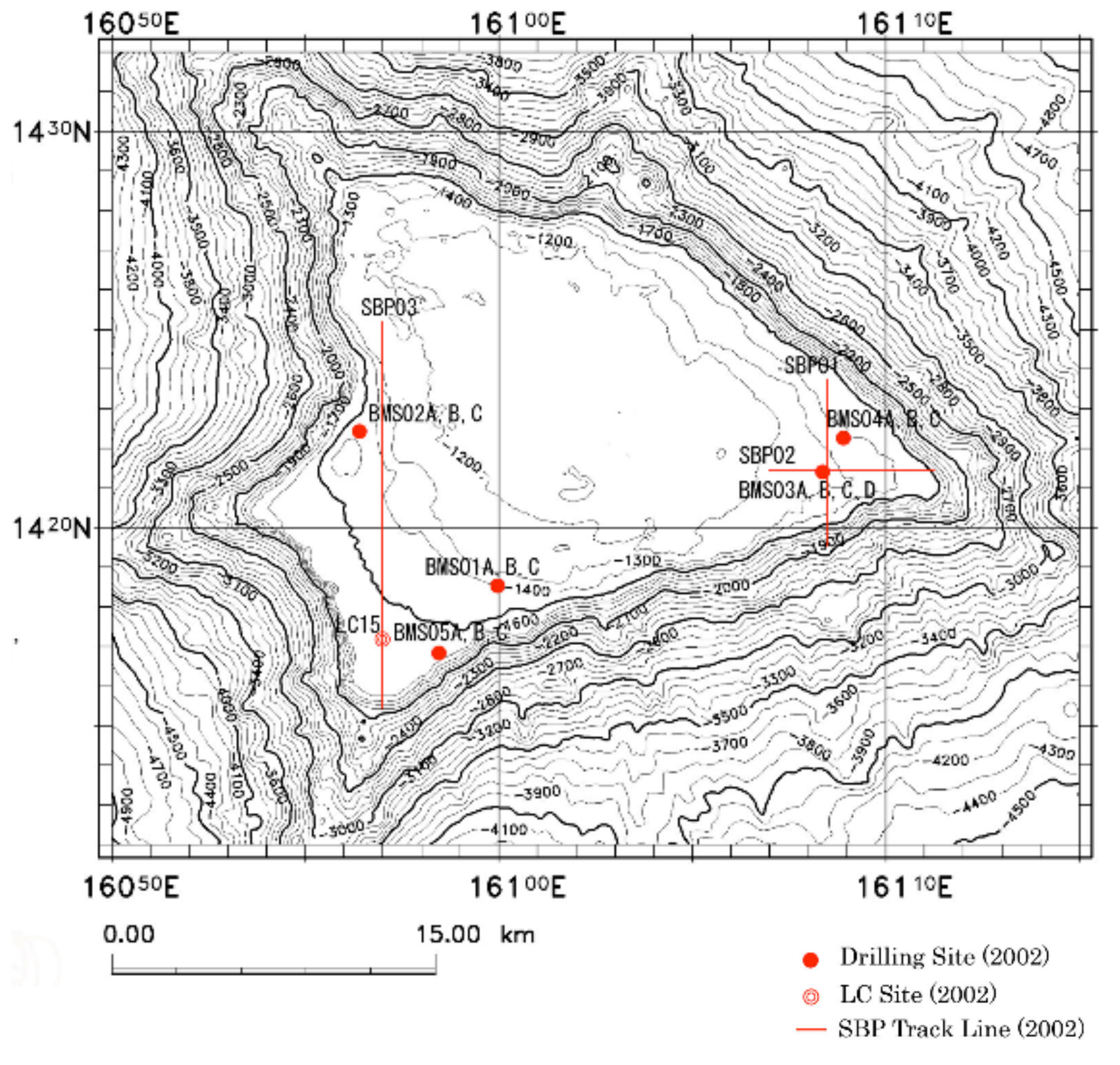


Figure 5. Bathymetry map of MS01 with drill site locations.

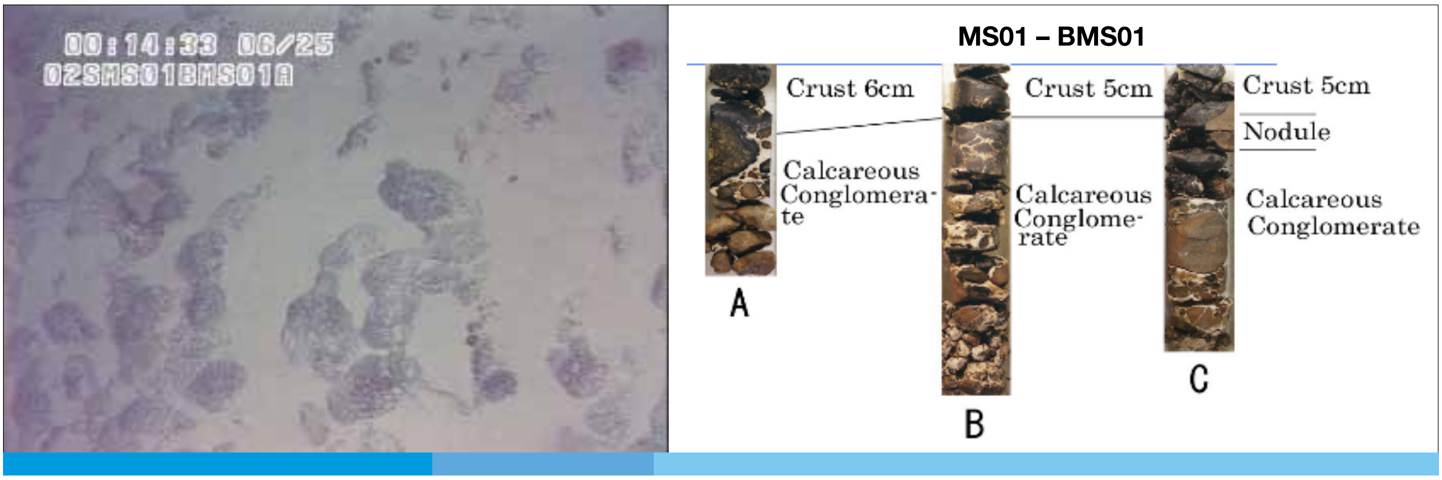


Figure 6. Cobalt-rich crust at Seamount MS01. Crust and sediment exposures at drill location BMS01A (left), and the drill core columns for all the drill holes (i.e. A, B and C) at site BMS01 (right).

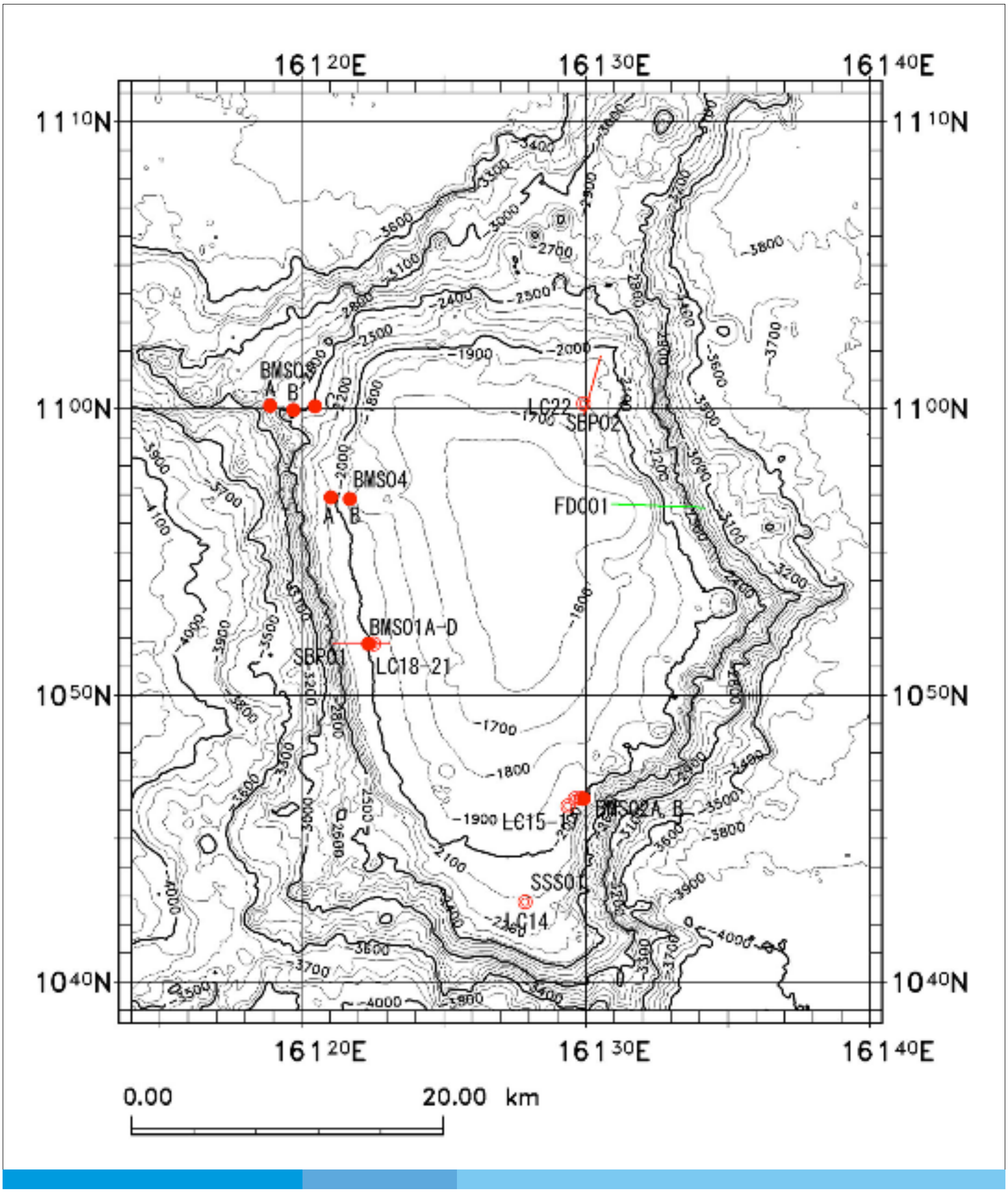


Figure 7. Bathymetry map of MS11 with drill site locations.

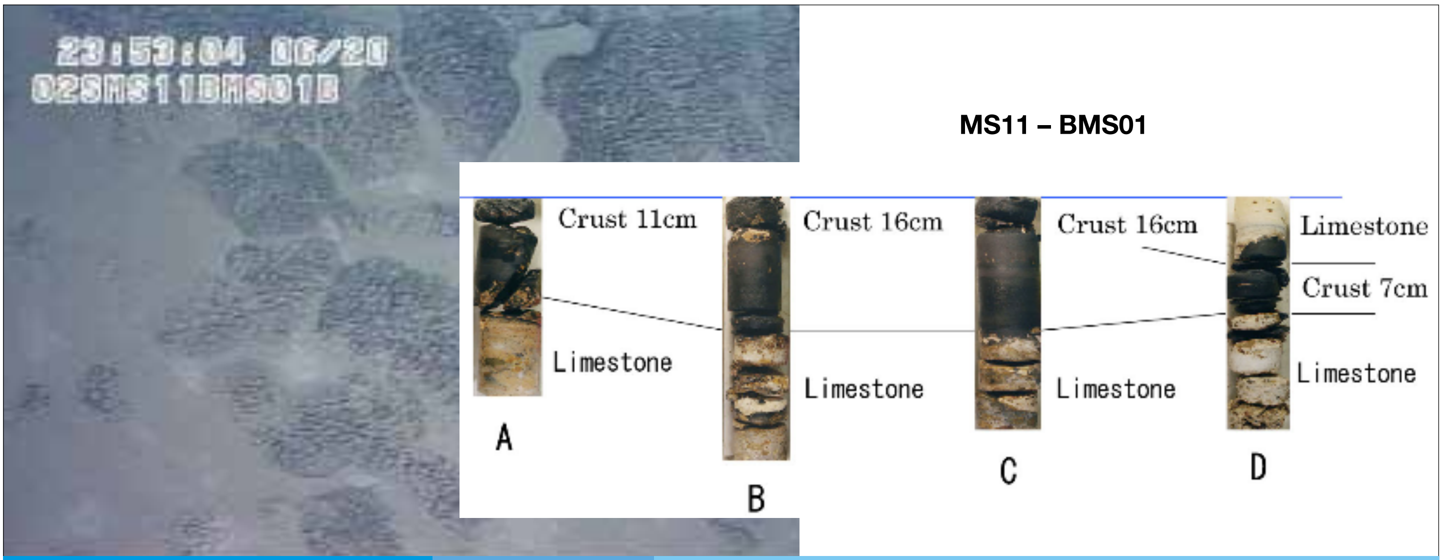


Figure 8. Cobalt-rich crust at Seamount MS11. Crust and sediment exposures at drill location BMS01B (left), and the drill core columns for all the drill holes (i.e. A, B, C and D) at site BMS01 (right).

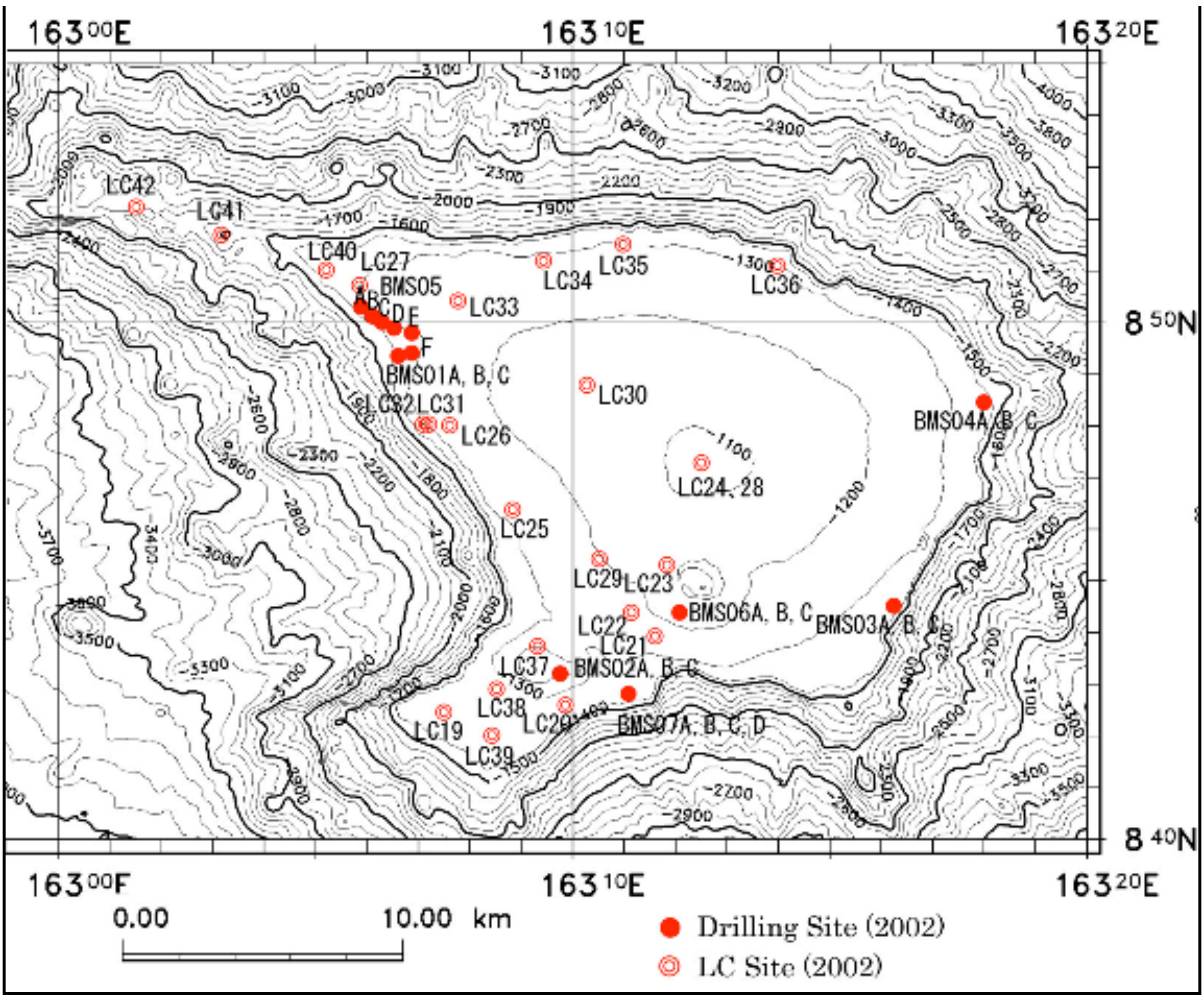


Figure 9. Bathymetry map of MS12 with drill site locations.

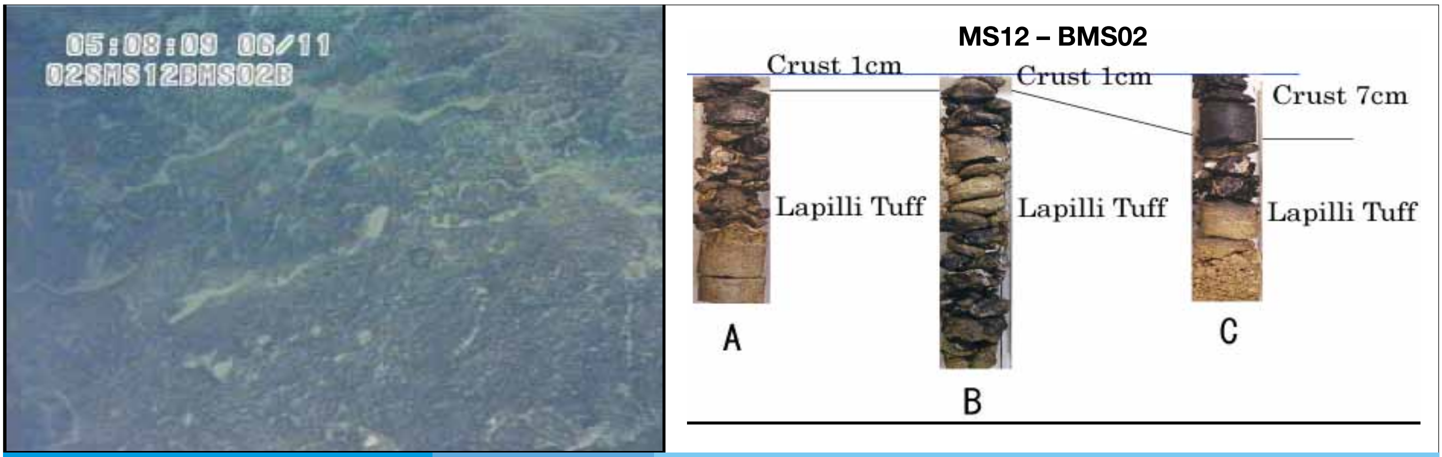


Figure 10. Cobalt-rich crust at Seamount MS12. Crust exposure at drill location BMS02B and the drill core columns of the three drill holes (i.e. A, B and C) at site BMS02.

Previous surveys have also revealed minor occurrences of other deep sea minerals such as manganese nodules and phosphate deposits within the EEZ of the RMI.

Metal Concentration and Distribution

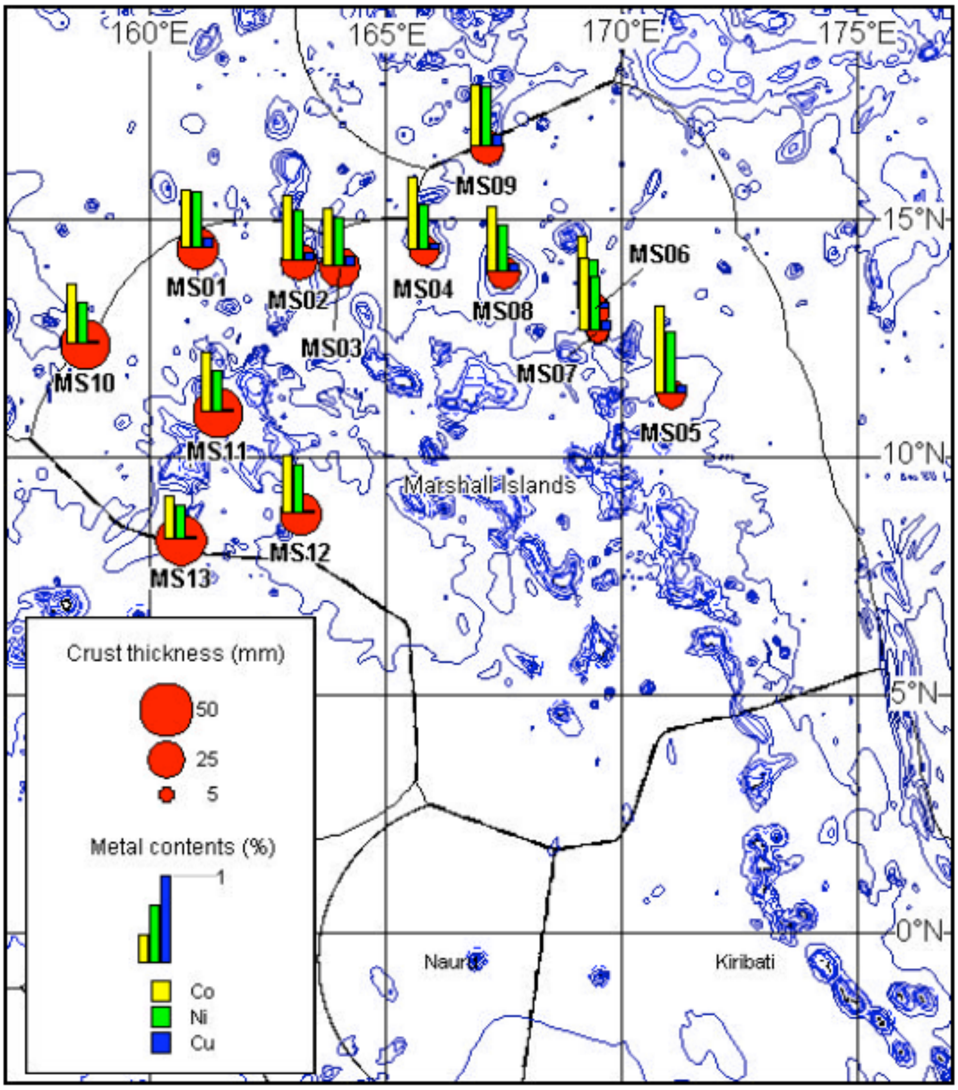


Figure 11. Thickness and metal contents of CRC at each seamount surveyed in the RMI.

The 1996 and 1998 survey results, using Deep-sea Camera with Finder (FDC), Sub-Bottom Profiler (SBP) and Side Scan Sonar (SSS) survey methods, suggest that thick crusts are widely distributed on the upper slopes and the marginal parts of the summits. The crust coverage estimated by FDC observations is shown in Table 2.

Samples were collected in almost all the 180 attempts on the 13 seamounts selected for study. Sampled crusts vary in thickness from a patina to more than 100 mm. The substrates are mainly basaltic and carbonate rocks. The average thickness and metal contents of crusts at each seamount are illustrated in Figure 11 and shown in Table 2.

Chemical composition analysis was carried out on 214 crust samples from 13 seamounts (MS01 – MS13). The average metal contents for crusts that occur on the thirteen seamounts are: Co 0.71 %, Ni 0.56 %, Cu 0.09 %, Mn 22.86 % and Fe 14.27 %.

Summary of Results

The summary of the 1996 and 1998 Japan-SOPAC survey results are tabulated in Table 2 below.

Table 2. Summary results of the cobalt-rich crust survey within the EEZ of the RMI.

Seamount		MS01	MS02	MS03	MS04	MS05	MS06	MS07	MS08	MS09	MS10	MS11	MS12	MS13
Type of Seamount		Guyot	Guyot	Guyot	Guyot	Peaked	Guyot	Peaked	Guyot	Guyot	Guyot	Guyot	Guyot	Peaked
Dimension (km x km)		70 x 60	55 x 50	58 x 70	60 x 60	50 x 50	40 x 50	50 x 50	130 x 100	70 x 70	22 x 20	28 x 45	40 x 30	25 x 50
Height (m)		4,000	4,200	3,500	3,500	3,800	3,600	3,100	3,600	3,900	4,300	2,700	3,860	3,610
Depth to Summit (m)		1,040	1,330	1,740	980	950	1,580	1,750	1,350	1,140	1,290	1,495	1,035	1,385
Occurrence *		C, B with minor N	C with minor B	C with F sand	C with minor N	N and B	Minor C	N with minor C	C with minor N	B, N, C	C	C	C with minor N	C with minor N
Coverage (%)		0 - 90	30 - 80	30 - 100	0 - 100	0 - 90	0 - 100	0 - 20	10 - 90	0 - 100	80 - 90	30 - 90	60 - 95	0 - 90
Average Thickness (mm)		33	24	30	18	17	19	17	21	22	44	38	33	46
Average Grade	Co (%)	0.67	0.70	0.62	0.76	0.91	0.76	0.83	0.70	0.71	0.69	0.69	0.67	0.50
	Ni (%)	0.62	0.54	0.55	0.52	0.69	0.56	0.61	0.55	0.66	0.47	0.48	0.56	0.39
	Cu (%)	0.12	0.10	0.14	0.09	0.12	0.10	0.13	0.10	0.12	0.05	0.05	0.05	0.04
	Pt (ppm)	0.46	0.48	0.57	0.33	0.43	0.36	0.44	0.45	0.42	0.67	0.61	0.47	0.36

* Crust Type: C – crust; B – Cobble; M – Massive; N – Nodule; S – Slab; F sand – Foraminifera sand.

2002 Drilling Results

The 2002 drilling results at seamounts MS01, MS11 and MS12 are summarised in Table 3 below.

Table 3. Summary of the 2002 drilling results for Seamounts MS01, MS11 and MS12.

Seamount	Exposed Area (km^2)	Ave thickness (mm)	Average Grade			
			Co (%)	Ni (%)	Cu (%)	Pt (ppm)
MS01	470	59	0.44	0.65	0.12	0.87
MS11	656	132	0.34	0.39	0.12	0.38
MS12	234	70	0.46	0.57	0.05	0.40

Comparing the survey results of MS01 in 2002 and 1996, Co is low and Pt is high in 2002. One possible reason for this is that dredge and Large Corer (LC) samplings collected incomplete cobalt crust samples dominated by outer layer during the 1996 survey. Layer-by-layer analysis of the crust sample shows that Co decreases from the outer layer to inner layer. On the other hand for MS11, Co and Pt are low and Cu is high in 2002 compared to the 1998 results. For MS12, the 2002 Co grade is low in 2002 compared to the 1998 results.

Cobalt-rich Crusts Resource Estimation

Two separate mineral resources estimation were conducted for the CRC resources that occur at the surveyed seamounts within the EEZ of the RMI. The first was carried out after the survey of the thirteen seamounts in 1996 and 1998 whilst the second was performed after the completion of the 2002 drilling program.

The first resource estimate confirms a total inferred resource of 186 million tonnes of crusts that exist on the thirteen seamounts containing 1,261,500 tonnes Co, 998,900 tonnes Ni, 156,500 tonnes Cu and 900 tonnes Pt. The details are shown in Table 4 below.

Table 4. Estimates of crust and metal resources base on the 1996 and 1998 surveys within the EEZ of the RMI.

Seamounts	^ Inferred Resources (tonnes)	Metal Resources (tonnes)			
		Co	Ni	Cu	Pt
MS01	20,341,000	134,252	130,184	26,444	93
MS02	10,323,000	76,393	59,875	10,323	49
MS03	19,979,000	133,862	111,885	25,973	113
MS04	7,381,000	61,998	38,380	5,905	24
MS05	2,711,000	27,108	18,976	2,982	12
MS06	3,004,000	24,936	17,124	2,704	11
MS07	941,000	7,902	5,926	1,129	4
MS08	21,189,000	156,802	116,542	21,189	95
MS09	13,767,000	96,370	93,617	19,274	58
MS10	16,804,000	115,945	78,977	8,402	112
MS11	23,938,000	165,171	114,901	11,969	146
MS12	19,147,000	128,287	109,139	9,574	89
MS13	26,505,000	132,526	103,370	10,602	97
Total	**186,030,000**	**1,261,552**	**998,896**	**156,470**	**903**

^ Inferred category of mineral resources estimation refers to the lowest level of geological confidence hence cannot be mined on its own. Detailed work is required to upgrade resources to minable categories.

The second resource evaluation was performed for seamounts MS01, MS11 and MS12 only. The previous estimates were reviewed based on new data collected during the 2002 survey. The 2002 revised inferred resources and metal quantities significantly increase compared to the 1996 and 1998 corresponding resources for these three seamounts (see Table 4). The revised mineral resources are shown in Table 5 below.

Table 5. Resource estimation for MS01, MS11 and MS12 based on the 2002 survey results.

Seamounts	Inferred Resources (tonnes)	Metal Resources (tonnes)		
		Co	Ni	Pt
MS01	55,500,000	244,000	360,000	48.3
MS11	173,200,000	589,000	693,000	65.8
MS12	32,800,000	151,000	187,000	13.1
Total	**261,500,000**	**984,000**	**1,240,000**	**127**

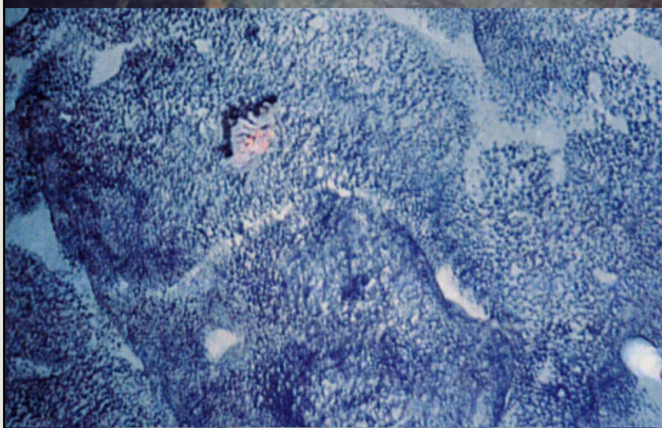
Conclusion

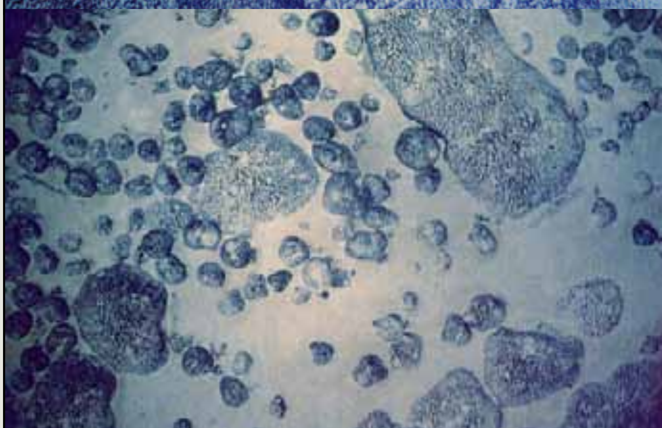
The seamounts in the western part of the RMI's EEZ have significant CRC potential whereas the seamounts in the northern part of Ratak Chain (eastern part of the EEZ) have moderate potential. Additionally, resource assessments to date have concluded that crusts are thicker in the western seamounts while cobalt grade is higher in the crusts that occur on the eastern seamounts.

The seamounts of the RMI appear to become older to the north / northwest. The base layer of the crust tends to thicken with age, and the cobalt content tends to increase toward the surface layer. This best explains the trend of occurrence and abundance of the CRC that occur within the EEZ of the RMI.

The 2002 drilling results reveal the true thickness and unbiased metal grades for the three seamounts surveyed. The relatively higher cobalt grades for samples collected on Seamount MS01 in 1996 and on Seamounts MS11 and MS12 in 1998 can be attributed to poor methods of sampling that resulted in the collection of samples dominated by the outer layer of the crusts. The cobalt grade is higher at the outer crust layer compared with that of the inner layers.

These survey results confirm that the EEZ of the RMI has one of the best potentials for CRC resource among the Pacific Islands EEZs surveyed. These deposits represent good resource potential for cobalt, nickel, platinum, and possibly other metals. Additional exploration is needed to better delineate the locations of thick and high-grade crusts, and also to map in detail the topography of previously surveyed seamounts.





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