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Exploration and mine site model applied to block selection for cobalt-rich ferromanganese crusts and polymetallic sulphides

Part I: Cobalt-rich ferromanganese crusts

Note by the Secretariat*

I. Introduction

1. During the eleventh session of the International Seabed Authority in 2005, the Council of the Authority completed a first reading of the draft regulations on prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area (hereinafter referred to as "the draft regulations"). At the conclusion of that first reading, the Council considered that further explanation and elaboration was required with respect to certain aspects of the draft regulations.

2. With respect to the size of areas for exploration, the Council requested that further information be provided on the proposed system of allocating exploration blocks and the way in which it might operate in practice, as well as on the proposed schedule for relinquishment and its consistency with the provisions of the United Nations Convention on the Law of the Sea. The present paper provides a scientific basis for the selection and quantification of parameters that can be used to define a seamount mine site for cobalt-rich crusts.

3. The parameters that will ultimately be used to choose a cobalt-rich ferromanganese crust mine site are not yet known. However, reasonable assumptions can be made that will bracket the likely characteristics of a mine site (see annex I, table 1). From that range of possibilities, a set of conditions have been selected, which are used to illustrate the selection process of lease blocks on seamounts for the exploration phase and mining operations for cobalt-rich crusts.

* Prepared with the assistance of a consultant, James R. Hein, United States Geological Survey.

The analysis presented is based on present state-of-knowledge of the morphology and size of seamounts and the distribution and characteristics of cobalt-rich crusts. The illustrations are not intended to be an economic evaluation, so the crust grade (i.e., content of cobalt, nickel, copper, manganese etc.) is not considered. Only those parameters that directly apply to determining lease-block sizes and the allocation and relinquishment of blocks during the exploration phase are considered. The rationale for those determinations are also discussed. Many seamounts, with a range of appropriate ore grades, do occur within the bounds of the examples illustrated below.

4. The surface areas of 34 typical north-equatorial Pacific guyots (flat-topped seamounts) and conical seamounts were measured (see annex II, fig. 1). Surface areas were determined using the ArcView 3-D Analyst and the amount of sediment versus hard-rock areas were calculated from side-scan sonar backscatter images. The surface areas of the 19 guyots and 15 conical seamounts vary from 4,776 to 313 square kilometres (see annex II, fig. 2). The total area of the 34 seamounts is 62,250 square kilometres, covering a geographic region of 506,000 square kilometres, although all seamounts within that region were not measured. The average surface area of the 34 seamounts is 1,850 square kilometres. The amount of surface area above 2,500 metres water depth at which mining is likely to occur (see below) averages 515 square kilometres (range 0-1,850 square kilometres). Guyots are bigger than conical seamounts (annex II, fig. 1) because guyots at one time grew large enough to be islands before erosion and subsidence took place. The conical seamounts never grew large enough to breach the sea surface.

II. Assumptions and calculations used for the model mine site

5. For many guyots and seamounts, the surface area that is likely to be mined is less than the area that exists above 2,500 metres water depth because of sediment cover, rough or steep topography, biological corridors set aside and other factors (see annex II, fig. 2).

A. Crust exposure/sediment cover

6. Seamounts with more than about 60 per cent sediment cover are unlikely to be considered for mining in favour of more promising seamounts, although the cut-off percentage will be determined in part by the overall size of the seamount. The following calculations are based on the range of 5 to 60 per cent sediment cover and use 60 per cent sediment cover as a worst-case scenario. A reduction of seamount surface area above 2,500 metres by 60 per cent leaves a remaining area of 204 square kilometres (485 square kilometres for 5 per cent sediment cover) for the average seamount that could potentially be mined, and an area of about 528 square kilometres (1,254 square kilometres for 5 per cent sediment cover) of the largest seamount measured for the present analysis that could potentially be mined (see annex II, fig. 2).

B. Area loss due to impediments to mining

7. The area not lost to sediment cover will be further reduced because of prohibitive small-scale topography, unmined biological corridors and other impediments to mining; a further 70 per cent reduction to the non-sediment-covered area is considered a worst-case scenario. Consequently, for the largest seamount measured, a worst-case scenario would yield as little as 158 square kilometres (376 square kilometres for 5 per cent sediment cover) for mining. For the average seamount, as little as 61 square kilometres (146 square kilometres for 5 per cent sediment cover) might be available for mining.

C. Annual production

8. The annual tonnage required to support a viable mining operation is not known and will depend in part on the global market for metals at the time of mine development. Estimates for annual tonnage production have varied widely and in many cases are not useful because it was not specified whether dry weight or wet weight was being considered. The most common suggestions for production range from about 0.70 to 2 million wet tonnes per year. The basis used for the model mine site is 1 million wet tonnes per year and a wet bulk density for crusts of 1.95 grams per cubic centimetre (see annex I, table 2).

D. Crust thickness and square-metre tonnage

9. Considered as a worst-case scenario is a mean crust thickness of 2 centimetres (39 kilograms wet weight of crust per square metre of seabed) and 2 million wet tonnes per year production, which would require the mining of 1,026 square kilometres of seabed to satisfy a 20-year mining operation (513 square kilometres for 20 years of 1 million wet tonnes annual production; see annex I, tables 1 and 2).

10. Used as a best-case scenario is a mean crust thickness of 6 centimetres (117 kilograms wet weight per square metre) and 1 million wet tonnes per year production, which would require the mining of 171 square kilometres of seabed during 20 years of operation (342 square kilometres for 2 million wet tonnes annual production; see annex I, table 2).

11. Used for the model mine site is a mean crust thickness of 2.5 centimetres (48.75 kilograms wet weight per square metre) and 1 million wet tonnes annual production, which would require the mining of 410 square kilometres of seabed during 20 years of operation (annex I, tables 1 and 2). Scientific exploration has shown that there exist tens of square-metre areas on seamounts with mean crust thicknesses of around 14 centimetres, but it is not known how extensive those areas might be. A mean crust thickness of 14 centimetres would yield an incredible 273 kilograms wet weight of cobalt-rich crusts per square metre of seabed.

E. Number of seamounts

12. From the data on seamount sizes and the areas that will likely be available for mining (see annex II, fig. 2), it can be concluded that about 1.1 to 2.6 large guyots

would be needed for the model 20-year mining operation, or about 2.8 to 6.7 average-size seamounts. Larger seamounts exist than the largest one measured for the present statistical analysis and, under favourable conditions, a single seamount could support a 20-year mining operation (see the example below). In addition, seamounts and guyots do exist that have little sediment cover, relatively subdued topography and an average crust thickness of more than 2.5 centimetres; these are the seamounts that are likely to be mined.

III. Selection of lease-block size and exploration area

13. The block size best suited for exploration and that best suited to define a mine site differ. The choice of a lease-block size to define a mine site is somewhat arbitrary, although the size should be small enough so that areas with continuous coverage by crusts can be enclosed within a single block. Based on what little is known about the distribution of crusts on guyot summits, a block size of about 20 square kilometres (4.47 kilometres on a side, or 4x5 kilometres) is a reasonable size that in aggregate can successfully define a mine site. It is likely that those blocks will be strung together in a pattern that follows summit terrace, platform and saddle topography. About 25 such blocks strung together or clustered would comprise the model 20-year mine site consisting of about 500 square kilometres, all 25 blocks of which may be on the summit of one seamount, or perhaps split between two or more seamounts (see annex II, figs. 3-6). The 20 square kilometre block size also corresponds approximately to the area that will be mined annually for the model mining operation. Based on the range of seamount parameters discussed above (see also annex I, tables 1 and 2), block sizes of 10 to 40 square kilometres (3.16 to 6.32 kilometres on a side) would be considered reasonable for defining a mine site.

14. The choice of a lease-block size for exploration is also somewhat arbitrary, although it should be large enough that a limited number of seamounts would be included in a single licence. A reasonable block size would be 100 square kilometres, or five times the block size used to define a mine site. This 100 square kilometres need not form a square but must consist of contiguous 20 square kilometre sub-blocks (see examples below). The size of the area allotted for exploration is again somewhat arbitrary and has generally been considered to be about five times the area needed for a 20-year mine site. Using that number, the area of exploration would be 2,500 square kilometres for our model crust mine site (annex I, table 2). Thus, for the model mine site about twenty-five 100 square kilometre exploration blocks would be allocated.

15. It may be considered that exploration leases would cover most of the summit area of guyots above 2,500 meters water depth and that blocks would be relinquished as unfavourable areas are identified along a given summit. In reality, the interested parties will likely have a good idea, prior to applying for exploration licences, where the most promising crust blocks are located on a seamount and may request blocks on numerous seamounts in a region of previously defined promise. If that is not a desirable outcome, the dual lease-block size proposed in the present paper is a favourable compromise. Twenty square kilometre sub-blocks should be the size used for relinquishing territory and ultimately in defining the final mine site.

16. In summary, for the model mining operation, about twenty-five 100 square kilometre blocks would be leased for exploration, thus providing 2,500 square kilometres for each initial exploration licence. Within designated periods of time, groups of 20 square kilometre blocks would be relinquished until the 25 blocks of 20 square kilometres remain that will define the final 500 square kilometre 20-year mine site used as the example.

IV. Model mine sites

17. Two exploration/mine-site scenarios are presented. The first includes a very large seamount (seamount A) with little or no sediment cover above 2,500 metres water depth (annex II, figs. 3 and 4). Seamount A was not included in the statistical analysis of surface areas for the 34 seamounts discussed above; its surface area was measured subsequently, specifically for the present mining and exploration example. Seamount A has a total surface area of 9,309 square kilometres, with 2,939 square kilometres above 2,500 metres water depth. That is enough area to accommodate a single exploration licence of 2,500 square kilometres for the mine site parameters listed in annex I, tables 1 and 2. Figure 4 in annex II shows twenty-five 100 square kilometre blocks which were leased for exploration, each composed of five 20 square kilometre sub-blocks. Some of that exploration territory would be relinquished during two or more stages, ending up with twenty-five 20 square kilometre blocks that would define the final 500 square kilometre mine site (indicated by black dots).

18. The second example splits the exploration area between two nearby seamounts (annex II, figs. 3, 5 and 6, seamounts B and C). In this example, the twenty-five 100 square kilometre exploration blocks are not always contiguous. The final choice of twenty-five 20 square kilometre blocks for mining operations are also not always contiguous, but do occur in clusters (indicated by black dots).

V. Rationale for seamount selection parameters

19. The characteristics of seamounts and crusts that are most conducive to mining can be broadly defined as follows:

(a) Mining operations will take place around the summit region of guyots on flat or shallowly inclined surfaces, such as summit terraces, platforms and saddles, which may have either relatively smooth or rough small-scale topography. These are the areas in which there are the thickest and most cobalt-rich crusts. In contrast, conical seamounts are smaller in area overall and, most importantly, have much smaller areas above 2,500 metres water depth. Conical seamounts also have much more rugged summit topography than guyots. Much thinner crusts occur on the steep flanks of both guyots and conical seamounts. The flanks of atolls and islands will not be considered for mining because crusts are generally very thin on those edifices;

(b) The summit of the guyots that are most likely to be leased will not be deeper than about 2,200 metres and the terraces no deeper than about 2,500 metres. The 2,500 metre cut-off depth is important for several reasons. Guyot slopes are more rugged at depths greater than 2,500 metres, crusts are generally thinner, and

content of cobalt, nickel and other metals is generally lower. There are also technological reasons for mining at water depths as shallow as possible. Other cut-off water depths have been proposed in the literature, the most common being 2,400 metres. That is a valid depth to use, but would eliminate some areas of potentially thick crusts on seamounts. Another cut-off water depth that has been cited is 1,500 metres. Since the flanks of atolls and islands will not be mined, this leaves only a few very large seamounts with enough surface area to be considered for mining. Of the 34 typical seamount surface areas measured for the present analysis, only one has a summit area greater than 400 square kilometres (487 square kilometres) above 1,500 metres water depth (see below). In contrast, 15 of the 19 guyots have summit areas greater than 400 square kilometres above 2,500 metres water depth; only 1 of the 15 conical seamounts has a summit area of that magnitude. If 1,500 metres is used as the cut-off water depth, then a large number of seamounts would have to be mined to support a single 20-year mining operation. In general, the technological requirements needed to operate at 1,500 metres will not be much different from those needed to operate at 2,500 metres;

(c) Seamounts will be chosen that have little or no sediment on the summit region, which implies strong and persistent bottom currents. Sediment cover on the summits of guyots ranges from nearly completely sediment covered to nearly sediment free. Seamounts with more than 60 per cent sediment cover will likely be passed over in favour of guyots with more promising crust distributions. However, this cut-off area will depend in part on the overall size of the seamount, with a greater tolerance for more sediment cover on the largest seamounts;

(d) The summit region above 2,500 metres water depth will be large, at more than 400 square kilometres. This estimate is based on the size of equatorial Pacific guyot summits shallower than 2,500 metres water depth and the range of percentages of the summit area that is likely to be available for mining. This cut-off area yields the fewest number of seamounts that would be needed to support a 20-year mining operation. The mining of many seamounts for a single 20-year operation will likely be technologically and economically feasible, but may be harder to justify from an environmental point of view;

(e) The guyots will be Cretaceous in age because younger volcanic edifices will not have had sufficient time to accrete thick crusts. These older seamounts are the only ones that form large guyots with extensive summit areas that have remained stable enough (from gravity processes) to support crust growth for tens of millions of years;

(f) Areas with clusters of large guyots will be favoured because more than one guyot might be required to fulfil the tonnage requirements for a 20-year mine site;

(g) The thoroughness with which the mining operations recover the available crust deposits will depend on the extraction technique used, which is presently unknown. Therefore the range listed in table 1 of annex I is only an estimate. If recovery efficiency becomes an important issue, it is likely that areas with thicker crusts will be chosen to make up for inefficiencies in the collection process. For example, an area with a mean crust thickness of 2 centimetres with a 60 per cent recovery efficiency would yield a recovery of only 1.2 centimetres of crust. It is likely that such a deficiency would be ameliorated by mining thicker crust deposits with 3 to 4 centimetre mean thickness, thus yielding the desired tonnage per square

metre of seabed. Recovery efficiency of 80 per cent is considered in the model mine site;

(h) Guyots with thick crusts will be chosen. The detailed distribution of crust thicknesses is not known for any seamount, or known for broad areas of a single seamount. Thicknesses vary from less than 1 to more than 20 centimetres. Sites with crusts less than 2 centimetres thick will not be considered for mining and it is likely that large areas will be found with mean crust thicknesses in the range of 2 to 6 centimetres (see annex I, table 1). The cut-off thickness will depend on the method ultimately used for mining crusts, which is yet to be established. A mean crust thickness of 2.5 centimetres is used for the model mine site (annex I, tables 1 and 2);

(i) Summit areas with high grades (of cobalt, nickel, copper, manganese, platinum etc.) will be chosen.

20. These seamount and cobalt-rich crust characteristics are found mostly in the central Pacific region, especially the central and western parts of the northern equatorial Pacific. In that region, a great many seamounts occur within the Area and promising locations for potential mining occur within the Mid-Pacific Mountains, such as the region between Wake and Minami Torishima (Marcus) Islands, the Magellan Seamounts, seamounts between the exclusive economic zones of Johnston Island and the Marshall Islands, and Johnston Island and Howland and Baker Islands.

VI. Suggested revisions to draft regulations

21. The regulations as currently drafted (ISBA/10/C/WP.1/Rev.1) require the contractor to nominate blocks 100 square kilometres in size (in squares of 10 kilometres x 10 kilometres). One hundred such blocks may be selected for exploration (giving a total exploration area of 10,000 square kilometres prior to relinquishment). However, the blocks must be contiguous. The contractor must relinquish 75 of the original 100 blocks, giving a final mine site of 2,500 square kilometres.

22. The arguments set out in the present paper suggest that in the case of cobalt-rich crusts, providing the contractor can define precisely the areas of interest, only 500 square kilometres would be needed to sustain a mine site. Such precision can be obtained by reducing the basic block size from 100 square kilometres to 20 square kilometres. Blocks should be organized according to a grid system at fine scale, but could be either square or rectangular. The applicant should also be allowed to group blocks into non-contiguous clusters in order to take advantage of the geomorphology of seamount groups. The relinquishment schedule would remain the same.

23. These revisions are reflected in the draft clauses presented in annex III to the present paper.

Annex I

Tables

Table 1
Mine site parameters

Parameter	*Range*	*Model site*
Seamount area (km^2)[a]	>400	>600
Seamount slope (º)	0-25	0-5
Water depth (m)	<2 500	<2 500
Mean crust thickness (cm)	2-6	2.5
Crust exposure (%)	40-95	70
Crust recovery (%)	70-90	82
Annual production (tonnes)[b]	1.0-2.0	1.0
Area mined in 20 years (km^2)	171-1 026	500
Mine site block size (km^2)[c]	10-40	20
Exploration block size (km^2)[c]	100-200	100

[a] Above 2,500 metres water depth.
[b] Millions of wet metric tonnes, based on a density of 1.95 g/cm^3.
[c] Suggested possible range of block sizes for leasing.

Table 2
Area of seabed mined based on annual production and mean crust thickness (wet bulk density of 1.95 g/cm^3)

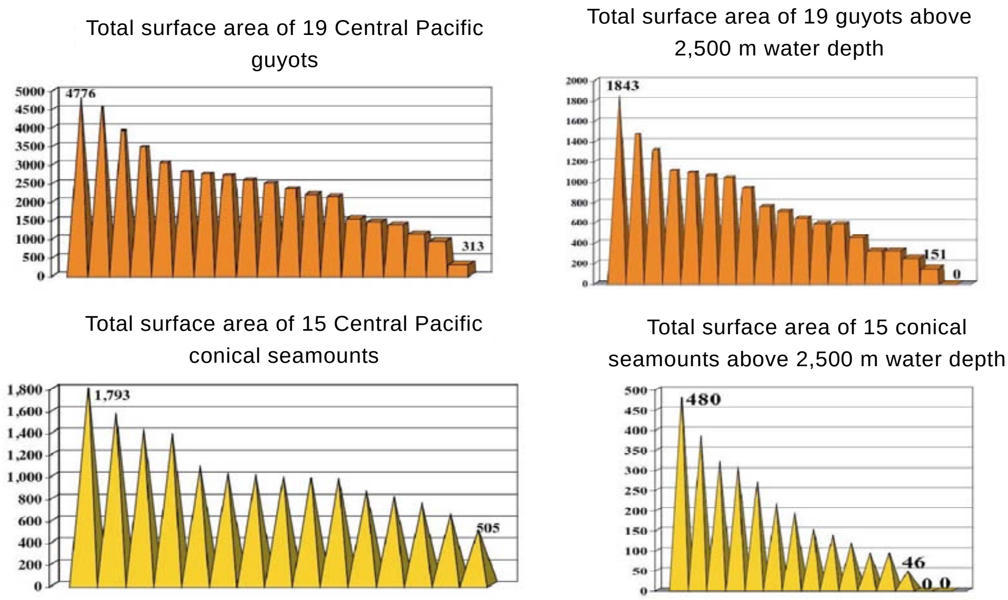
	Worst case	*Best case*	*Model site*
Mean crust thickness (cm)	2.0	6.0	2.5
Wet tonnage (kg/m^2)	39	117	48.75
Annual production (tonnes)[a]	2 000 000	1 000 000	1 000 000
Area mined per year (km^2)	51.3	8.55	20.5
Recovery efficiency (%)	70	90	82
Area mined per year (km^2)[b]	73.26	9.50	25.0
Area mined in 20 years (km^2)	1 465	190	500
Area for exploration (km^2)[c]	7 326	950	2 500

[a] Wet metric tonnes based on density of 1.95 g/cm^3.
[b] Calculated using the recovery efficiency and the tonnage per unit area.
[c] Arbitrarily set at five times the area mined during 20-year operation.

Annex II

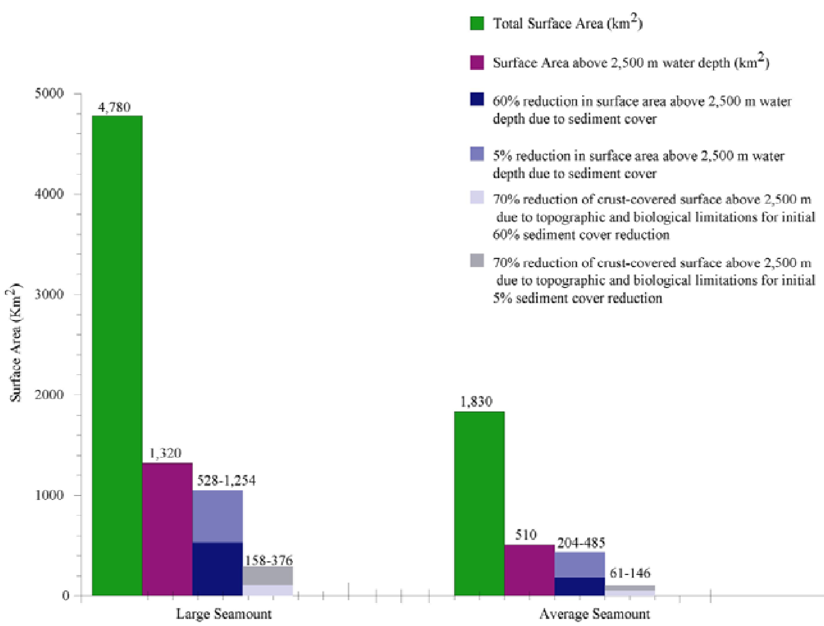
Figures

Figure 1



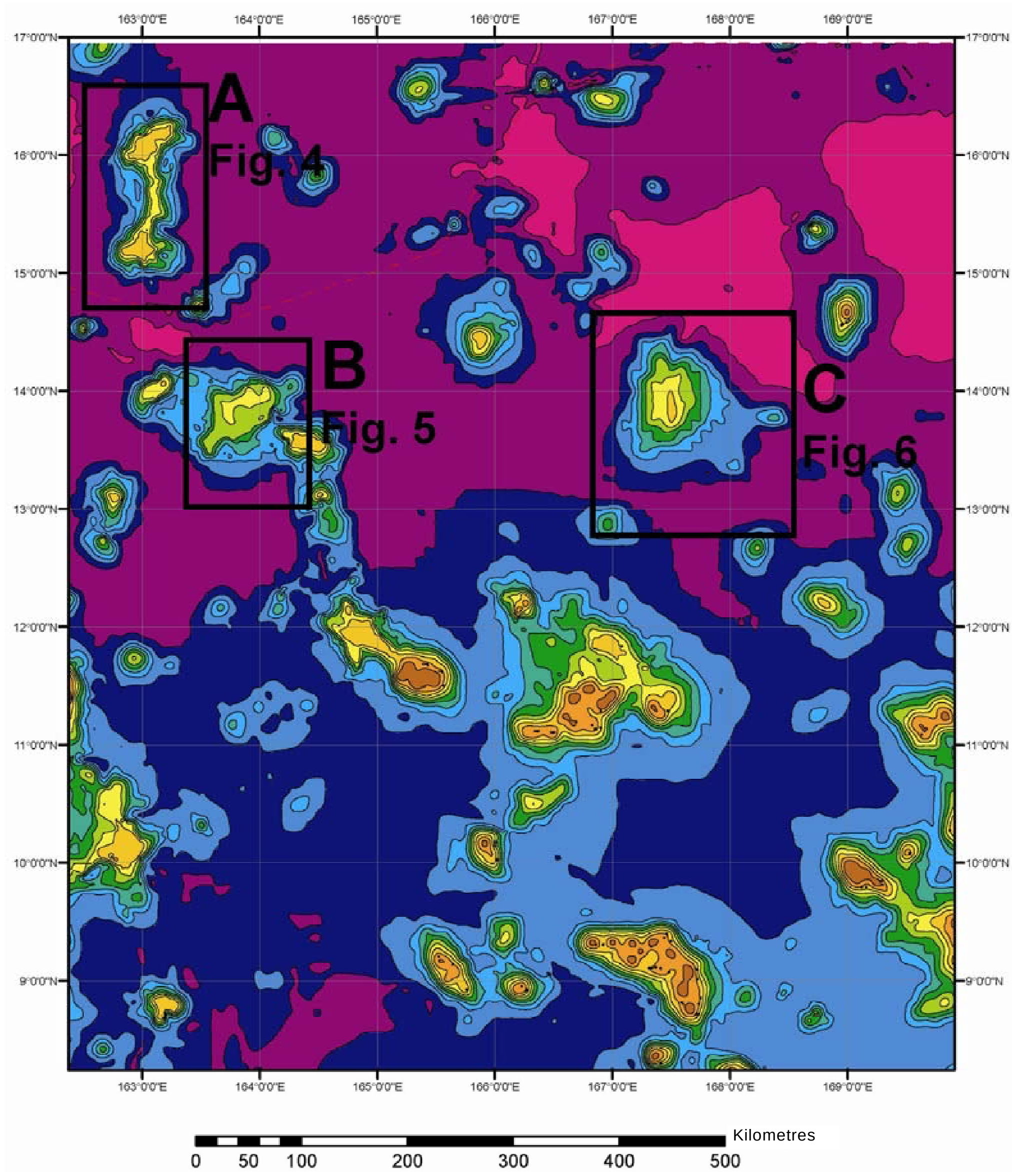
Surface area of 34 Central Pacific seamounts, in square kilometres.

Figure 2



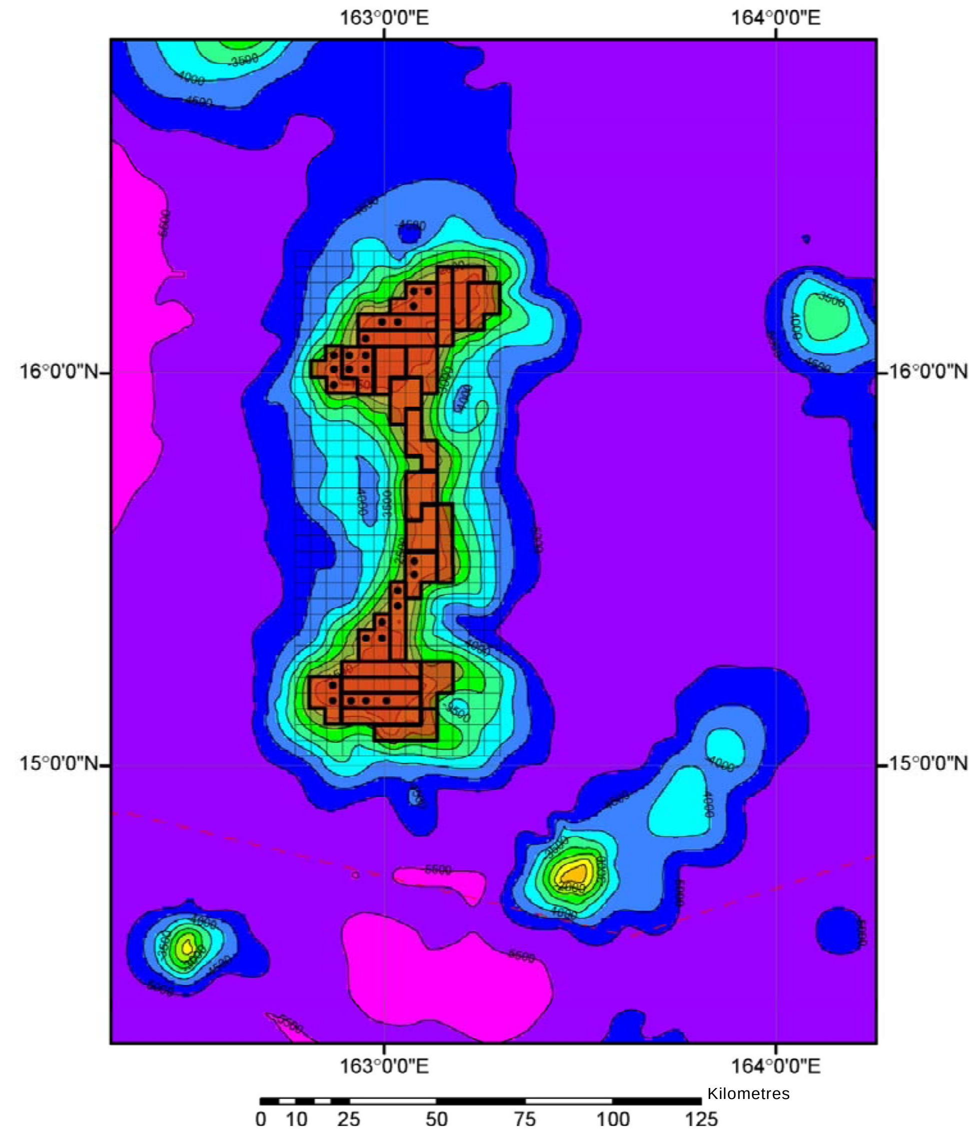
Surface area available for potential mine sites considering worst-case (60% sediment cover) and best-case (5% sediment cover) scenarios.

Figure 3



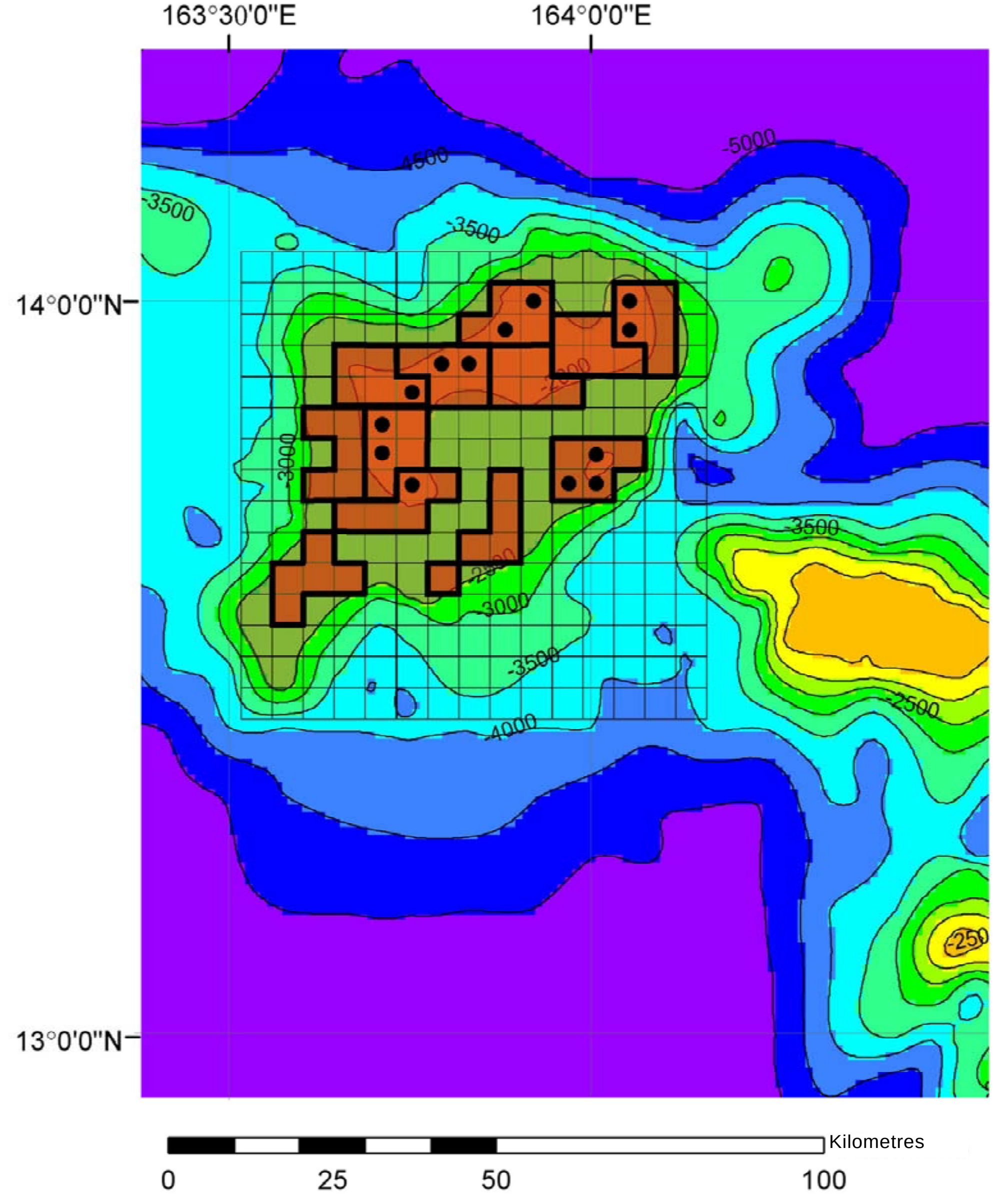
Seamounts A, B, and C are used for example exploration/mine site models (see figs. 4-6). The faint dashed red line marks boundary between the Marshall Islands exclusive economic zone to the south and international waters to the north — north-west Pacific.

Figure 4



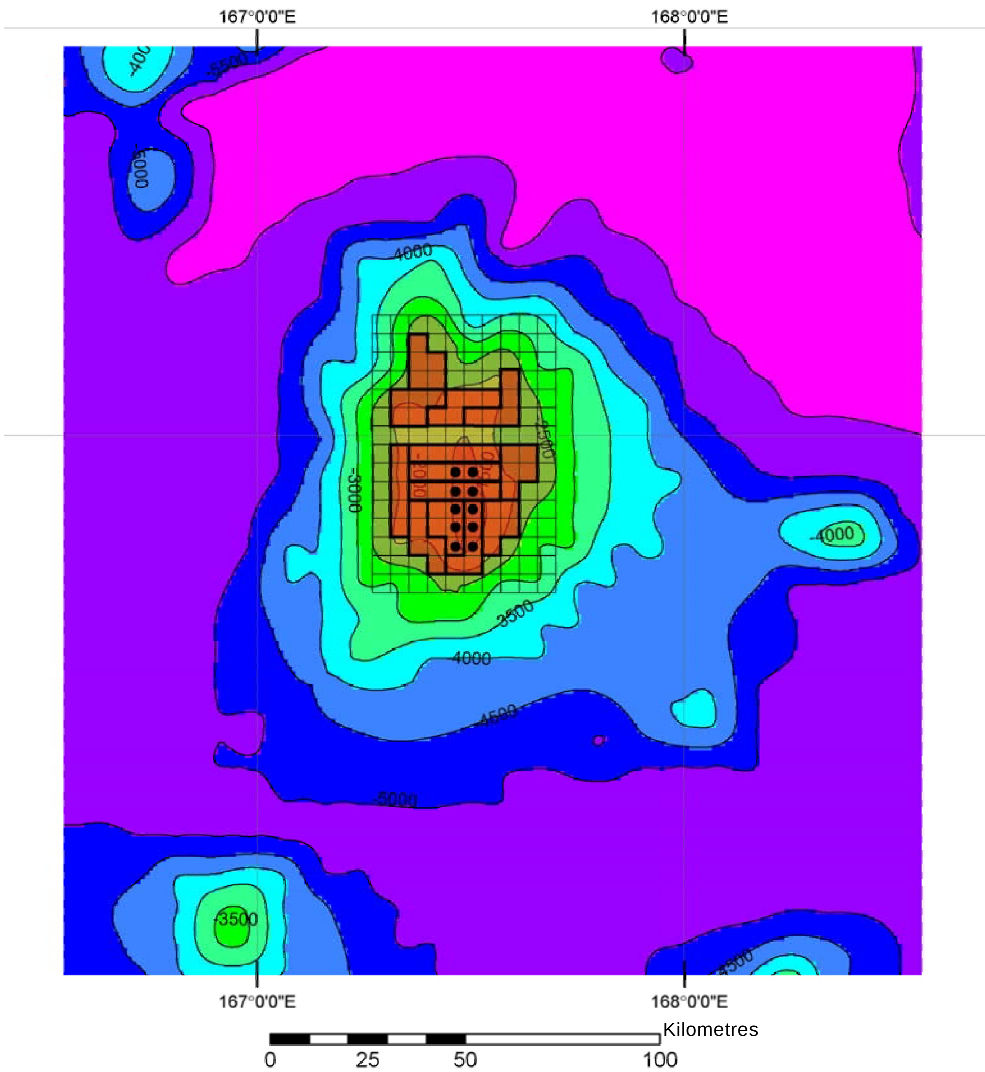
Exploration/mine site scenario 1, single seamount: seamount A with 20 km^2 grid; twenty-five 100 km^2 contiguous blocks define the exploration area (bold grid lines), whereas one hundred 20 km^2 sub-blocks are relinquished during the exploration phase. The twenty-five 20 km^2 blocks chosen for the final mine site are indicated by black dots.

Figure 5



Exploration/mine site scenario 2, multiple seamounts, first seamount: seamount B with 20 km^2 grid; twelve 100 km^2 contiguous and non-contiguous blocks define half of the exploration area (bold grid lines), whereas 20 km^2 sub-blocks are relinquished during the exploration phase. The thirteen 20 km^2 blocks chosen for half of the final mine site are indicated by black dots.

Figure 6



Exploration/mine site scenario 2, multiple seamounts, second seamount: seamount B with 20 km^2 grid; thirteen 100 km^2 contiguous and non-contiguous blocks define part of the exploration area (bold grid lines), whereas 20 km^2 sub-blocks are relinquished during the exploration phase. The twelve 20 km^2 blocks chosen for about half of the final mine site are indicated by black dots.

Annex III

Suggested revisions to the draft regulations[a]

Definition

A block is one or more cells of a grid as provided by the Authority, which may be square or rectangular in shape, no greater than 20 square kilometres.

Regulation 12
Total area covered by the application (cobalt-rich crusts)

1. The area covered by each application for approval of a plan of work for exploration for cobalt-rich crusts shall be comprised of not more than 100 blocks which shall be arranged by the applicant in clusters, as set out in paragraph 2 below.

2. Five contiguous blocks form a cluster of blocks. Two blocks that touch at any point shall be considered to be contiguous. Clusters of blocks need not be contiguous but shall be proximate and located within the same geographical area.

3. Notwithstanding the provisions in paragraph 1 above, where a contractor has elected to contribute a reserved area to carry out activities pursuant to article 9 of annex III to the Convention, in accordance with regulation 17, the total area covered by an application shall not exceed 200 blocks.

Regulation 27
Size of area and relinquishment

1. The contractor shall relinquish the blocks allocated to it in accordance with paragraphs 2, 3 and 4 of the present regulation.

2. By the end of the fifth year from the date of the contract, the contractor shall have relinquished: (a) at least 50 per cent of the number of blocks allocated to it; or (b) if 50 per cent of that number of blocks is a whole number and a fraction, the next higher whole number of the blocks.

3. By the end of the tenth year from the date of the contract, the contractor shall have relinquished: (a) at least 75 per cent of the number of blocks allocated to it; or (b) if 75 per cent of that number of blocks is a whole number and a fraction, the next higher whole number of the blocks.

4. At the end of the fifteenth year from the date of the contract, or when the contractor applies for exploitation rights, whichever is the earlier, the contractor shall nominate up to 25 blocks from the remaining number of blocks allocated to it, which shall be retained by the contractor.

5. Relinquished blocks shall revert to the Area.

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[a] See ISBA/10/C/WP.1/Rev.1.