Exploration and Mine Site Model Applied to Seamount Lease-Block Selection for Cobalt-Rich Crusts

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For the ISA
Introduction

Parameters that ultimately will be used to define an exploration area and mine site are unknown

Reasonable assumptions are used to bracket likely characteristics

A set of conditions is selected based on present state-of-knowledge of seamount morphology and size, and distribution of cobalt-rich crusts
Mining operations will take place around the summit region of guyots on flat or shallowly inclined surfaces: summit platforms, terraces, and saddles. These are the areas with the thickest and most cobalt-rich crusts. Much thinner crusts occur on steep slopes. Conical seamounts are too small, with rugged summits.

Seamount summits will not be much deeper than about 2200 m; terraces will not be deeper than about 2500 m. Slopes are more rugged below 2500 m. Crusts are thinner below 2500 m. The contents of Co, Ni, Cu, etc. in crusts are less below 2500 m.

Little or no sediment will occur on the summit platform, therefore, a region of strong and persistent bottom currents.

Rationale for seamount selection parameters
Rationale (continued)

- The summit region above 2500 m will be large, more than 400 km$^2$
  - Yields fewest seamounts needed to be mined

- The submarine flanks of islands and atolls will not be considered for mining

- Clusters of large seamounts will be favoured

- The seamounts will be old, of Cretaceous age
  - Crust thickness, slope stability, guyots with large summit areas

- Seamounts with thick crusts and high grades (Co, Ni, Cu, etc.)

- The central Pacific best fulfills all these criteria
Area calculation details

- Surface area of 34 typical seamounts calculated
- ArcMap’s 3-D analyst used for area calculations
- Sediment vs. hard-rock calculated from side-scan sonar back-scatter images
Typical Guyot

56 kilometers long
Terraces: smooth and rough
Large area above 2500 m
Debris apron
Typical Conical Seamount

14° slopes
Small area above 2,500 m
Rugged summit
Total surface area of 19 Central Pacific Guyots

Total surface area of 34 seamounts: 62,250 km²
Geographic area hosting 34 seamounts: 506,000 km²

25 km²/yr mining area
500 km²/20 yrs mining site
2,500 km² for exploration for mine sites

Total Surface Area of 15 Central Pacific Conical Seamounts
Total Surface Area of 19 Guyots above 2500 m water depth

Total Surface Area of 15 Conical Seamounts above 2500 m water depth

Total surface area of 34 seamounts above 2500 m: 17,470 km²

25 km²/yr mining area
500 km²/20 yrs mining site
2,500 km² for exploration for mine sites
## Average Seamount

*(Surface Area Statistics for 34 Seamounts)*

<table>
<thead>
<tr>
<th>Total Surface Area (km²)</th>
<th>Surface Area above 2500m water depth (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>1,850</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>1,450</td>
</tr>
<tr>
<td><strong>SD</strong>&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1,150</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td>310</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>4,775</td>
</tr>
<tr>
<td></td>
<td>515</td>
</tr>
<tr>
<td></td>
<td>325</td>
</tr>
<tr>
<td></td>
<td>470</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1,843</td>
</tr>
</tbody>
</table>

<sup>1</sup>Standard Deviation

25 km²/yr mining area  
500 km²/20 yrs mining area  
2,500 km² for exploration for mine sites
Actual surface area to be mined limited by:

- Crust exposure/sediment cover
  - Varies from nearly 0% to nearly 100%
  - Cut-off of 60% sediment cover, seamount size dependent
  - Worst case scenario: 60% reduction leaves 528 km² for largest seamount in data set (1,254 km² for 5% cover)

- Other impediments to mining
Other Impediments to Mining

- Prohibitive small-scale topography
- Biological corridors
- Unforeseen impediments
- Up to 70% further reduction in mining area

Worst case scenario: 70% reduction leaves 158 square kilometers available for the largest seamount in data set (376 square kilometers for 5% sediment cover)
Reduction in Mineable Area

Figure 2. Surface area available for potential mine sites considering worst-case (60% sediment cover) and best-case (5% sediment cover) scenarios.
Crust thickness and square meter tonnage

- Worst case: mean crust thickness of 2 cm = 39 kg/m² wet weight (density 1.95 g/cm³)
- Best case: mean crust thickness of 6 cm = 117 kg/m²
- Model mine site: 2.5 cm net thickness = 48.75 kg/m²
- Areas have been found with a mean crust thickness of 14 cm = an incredible 273 kg of Co-rich crusts per m² of seabed
Number of seamounts

Based on our data set of 34 measured seamounts:

- 1.1 to 2.6 large guyots or 2.8-6.7 average-size seamounts needed for a 20-year mining project.

- A single larger seamount could sustain a 20-year mining operation under favorable conditions.

- Large guyots with little sediment cover, subdued topography, and average crusts of >2.5 cm are most likely to be mined, all of which would reduce the number of seamounts needed for a 20-year mine site.
Selection of Lease-Block Size and Exploration Area

- Recommended exploration lease-block size is 100 km²
- The 100 km² blocks are composed of contiguous 20 km² sub-blocks
- 100 km² exploration blocks need not be contiguous
- The sub-block size should be small enough to ensure nearly continuous crust coverage within the sub-block
The exploration lease is defined as twenty-five 100 km² blocks, yielding 2,500 km² for exploration.

Relinquishment of unwanted territory will proceed using the 20 km² sub-blocks.

20 km² sub-blocks will be relinquished during 2 or 3 phases as unfavorable areas are identified.

A final 25 sub-blocks will be chosen for a 20-year mine site of 500 km²; on one seamount or portioned among two or more seamounts.
Summary of Exploration/Mine Blocks

- Twenty-five 100 km$^2$ blocks leased for exploration
- Yielding 2,500 km$^2$ per exploration license
- Groups of 20 km$^2$ blocks relinquished during several phases
- 25 sub-blocks of 20 km$^2$ will define the final 20-year mine site of 500 km$^2$
## Mine Site Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Model Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seamount area (km²)</td>
<td>&gt;400</td>
<td>&gt;600</td>
</tr>
<tr>
<td>Seamount slope (°)</td>
<td>0-25</td>
<td>0-5</td>
</tr>
<tr>
<td>Water depth (m)</td>
<td>&lt;2500</td>
<td>&lt;2500</td>
</tr>
<tr>
<td>Mean crust thickness (cm)</td>
<td>2-6</td>
<td>2.5</td>
</tr>
<tr>
<td>Sediment cover (%)</td>
<td>5-60</td>
<td>30</td>
</tr>
<tr>
<td>Crust recovery (%)</td>
<td>70-90</td>
<td>82</td>
</tr>
<tr>
<td>Mine block size (km²)</td>
<td>10-40</td>
<td>20</td>
</tr>
<tr>
<td>Exploration block size (km²)</td>
<td>100-200</td>
<td>100</td>
</tr>
</tbody>
</table>
## Area Mined

<table>
<thead>
<tr>
<th></th>
<th>Worst Case</th>
<th>Best Case</th>
<th>Model Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean crust thickness (cm)</td>
<td>2.0</td>
<td>6.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Wet tonnage (kg/m²)</td>
<td>39</td>
<td>117</td>
<td>48.75</td>
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<tr>
<td>Annual production (10⁶ tons)</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Area mined/year (km²)</td>
<td>51.3</td>
<td>8.55</td>
<td>20.5</td>
</tr>
<tr>
<td>Recovery efficiency (%)</td>
<td>70</td>
<td>90</td>
<td>82</td>
</tr>
<tr>
<td>Area mined/year (km²)</td>
<td>73.26</td>
<td>9.50</td>
<td>25.0</td>
</tr>
<tr>
<td>Area mined in 20 years (km²)</td>
<td>1465</td>
<td>190</td>
<td>500</td>
</tr>
<tr>
<td>Area for exploration (km²)</td>
<td>7326</td>
<td>950</td>
<td>2500</td>
</tr>
</tbody>
</table>
Model Mine Sites
Seamount A

- Large composite seamount
- Total surface area: 9,309 km²
- Area above 2,500 m water depth: 2,939 km²
- This seamount can accommodate a single 20-year mine site
Seamount B