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

James R. Hein
U.S. Geological Survey
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 (continued)

- The summit region above 2500 m will be large, more than 400 km²
  - 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></th>
<th><strong>Total Surface Area (km²)</strong></th>
<th><strong>Surface Area above 2500m water depth (km²)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>1,850</td>
<td>515</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>1,450</td>
<td>325</td>
</tr>
<tr>
<td><strong>SD†</strong></td>
<td>1,150</td>
<td>470</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td>310</td>
<td>0</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>4,775</td>
<td>1,843</td>
</tr>
</tbody>
</table>

†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 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 km$^2$ blocks, yielding 2,500 km$^2$ for exploration.

Relinquishment of unwanted territory will proceed using the 20 km$^2$ sub-blocks.

20 km$^2$ 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 km$^2$; 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>
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</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>
</tr>
<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>
Seamount A

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