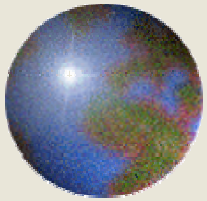
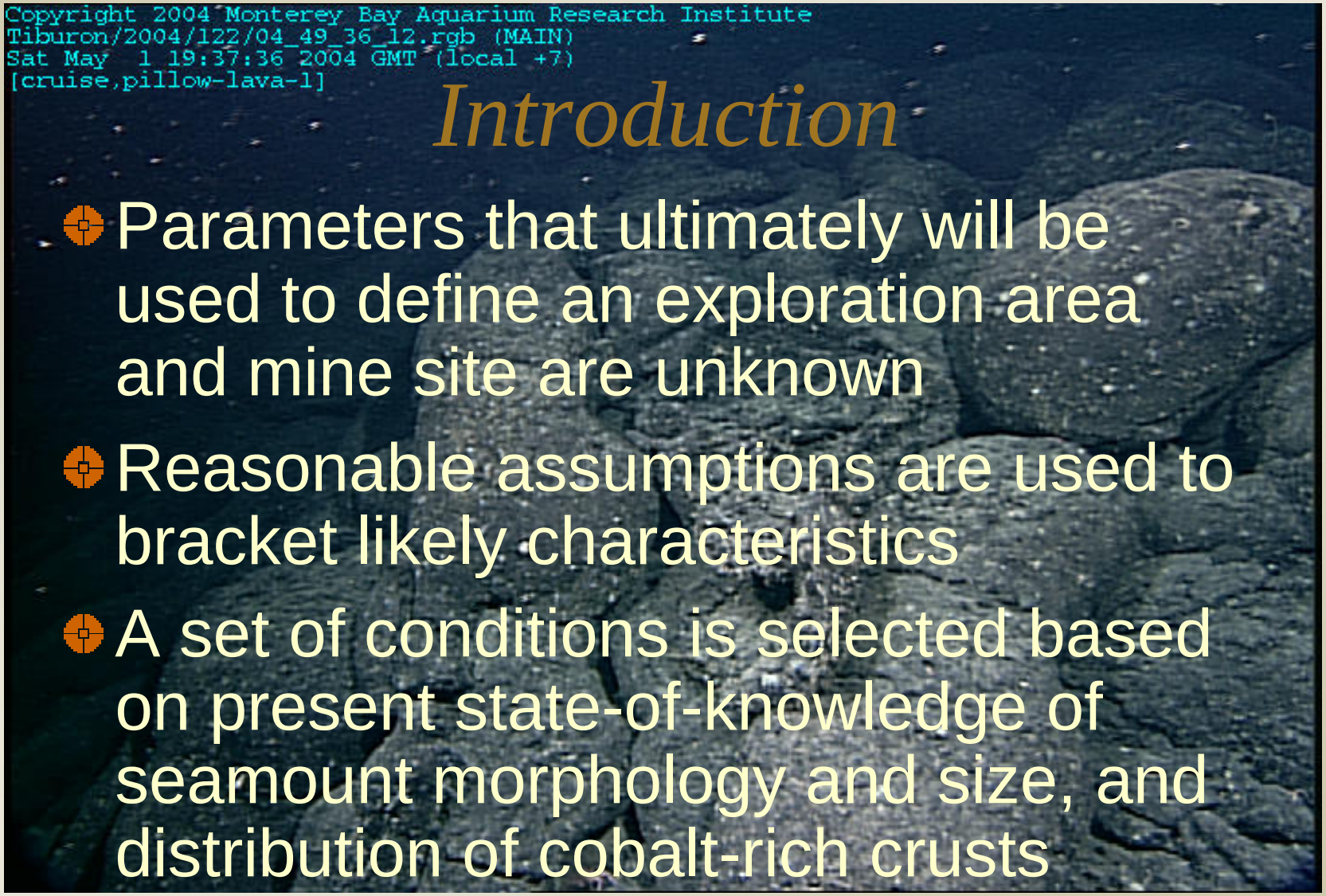


Exploration and Mine Site Model Applied to Seamount Lease-Block Selection for Cobalt-Rich Crusts

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

Rationale for seamount selection parameters

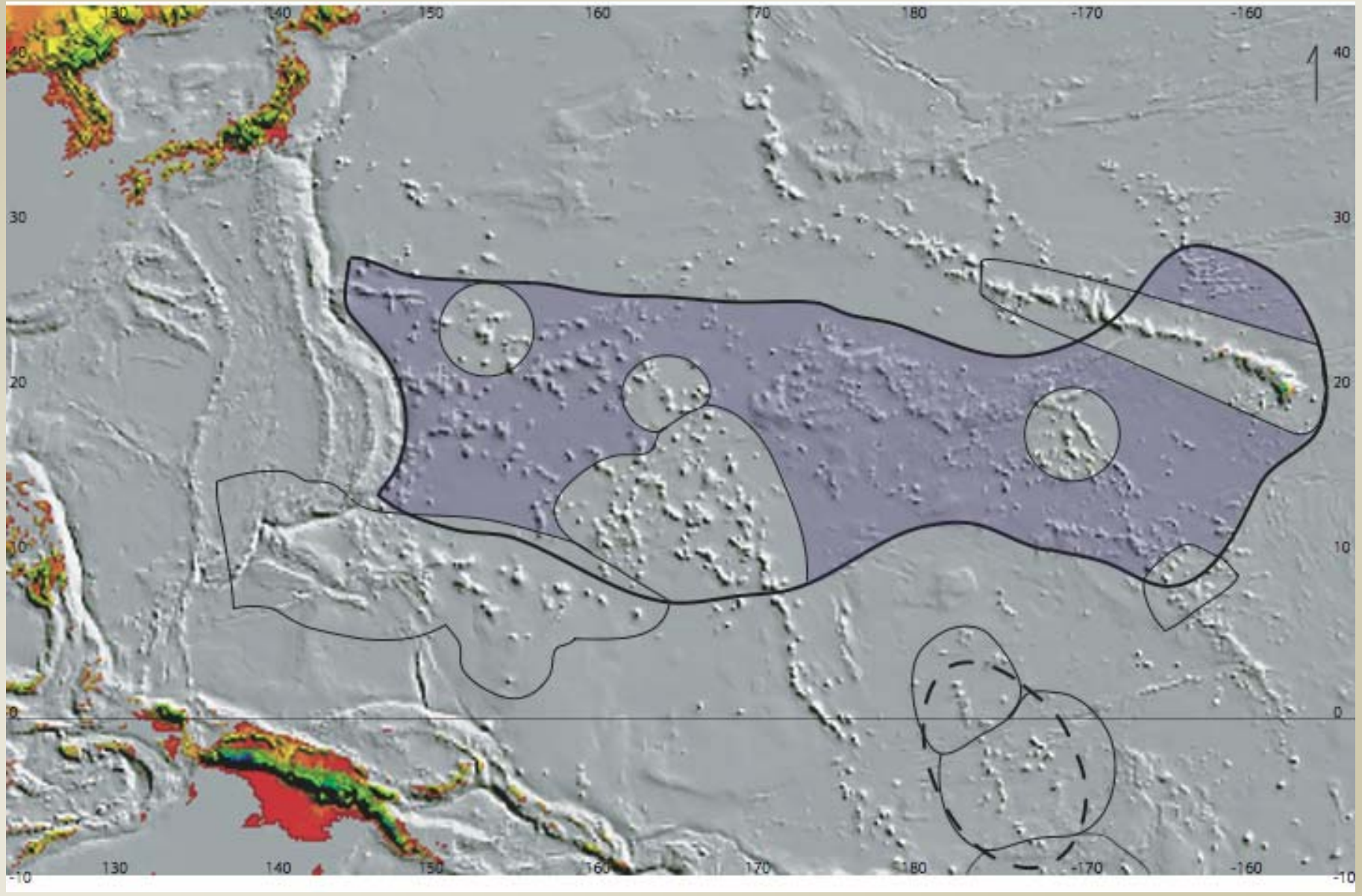
- Mining operations will take place around the summit region of guyots on flat or shallowly inclined surfaces: summit platforms, terraces, and saddles
  - These are the areas with the thickest and most cobalt-rich crusts
    - Much thinner crusts occur on steep slopes
  - Conical seamounts are too small, 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 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

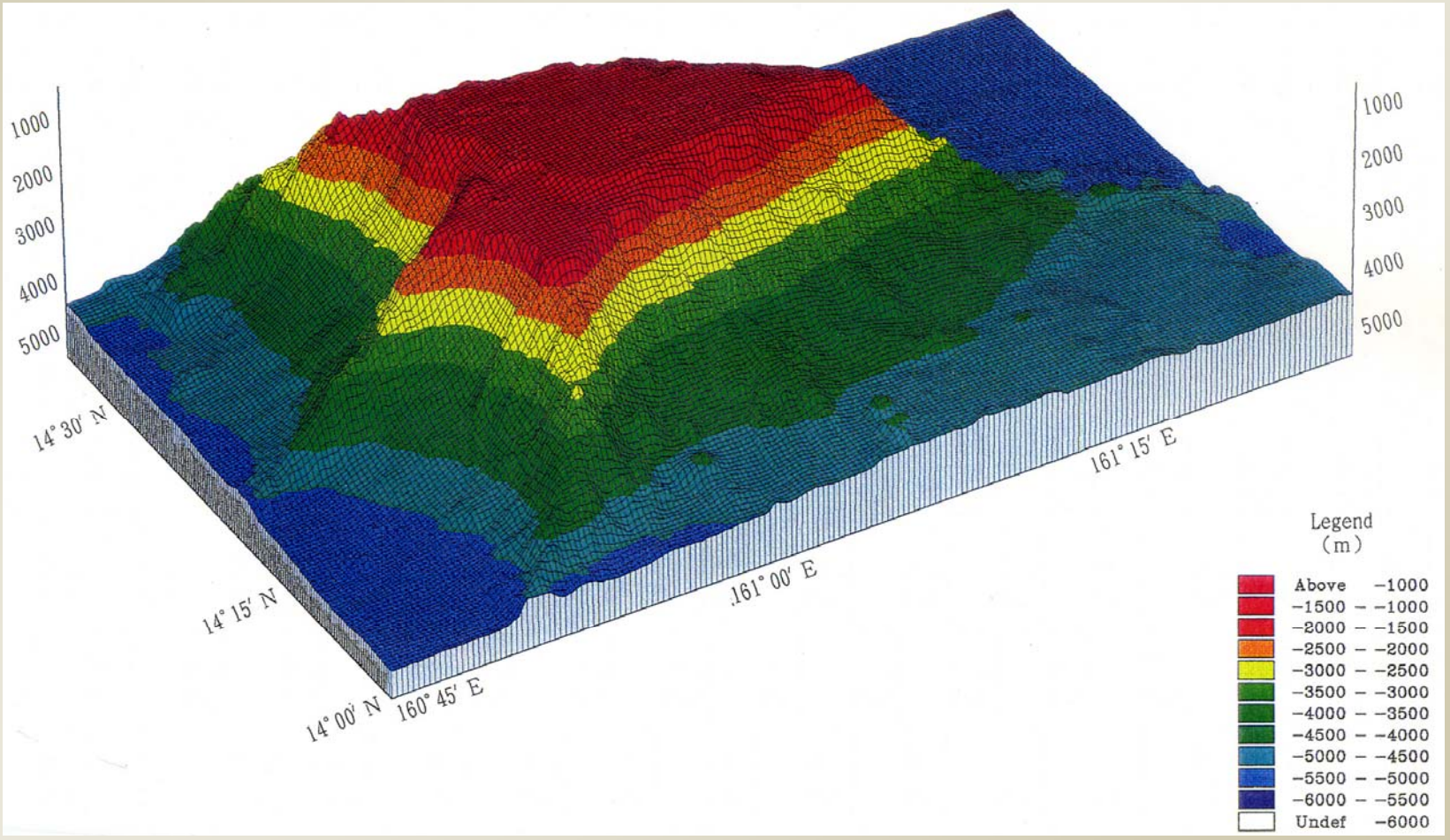

130
140
150
160
170
180
-170
-160
40
30
20
10
0
-10

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

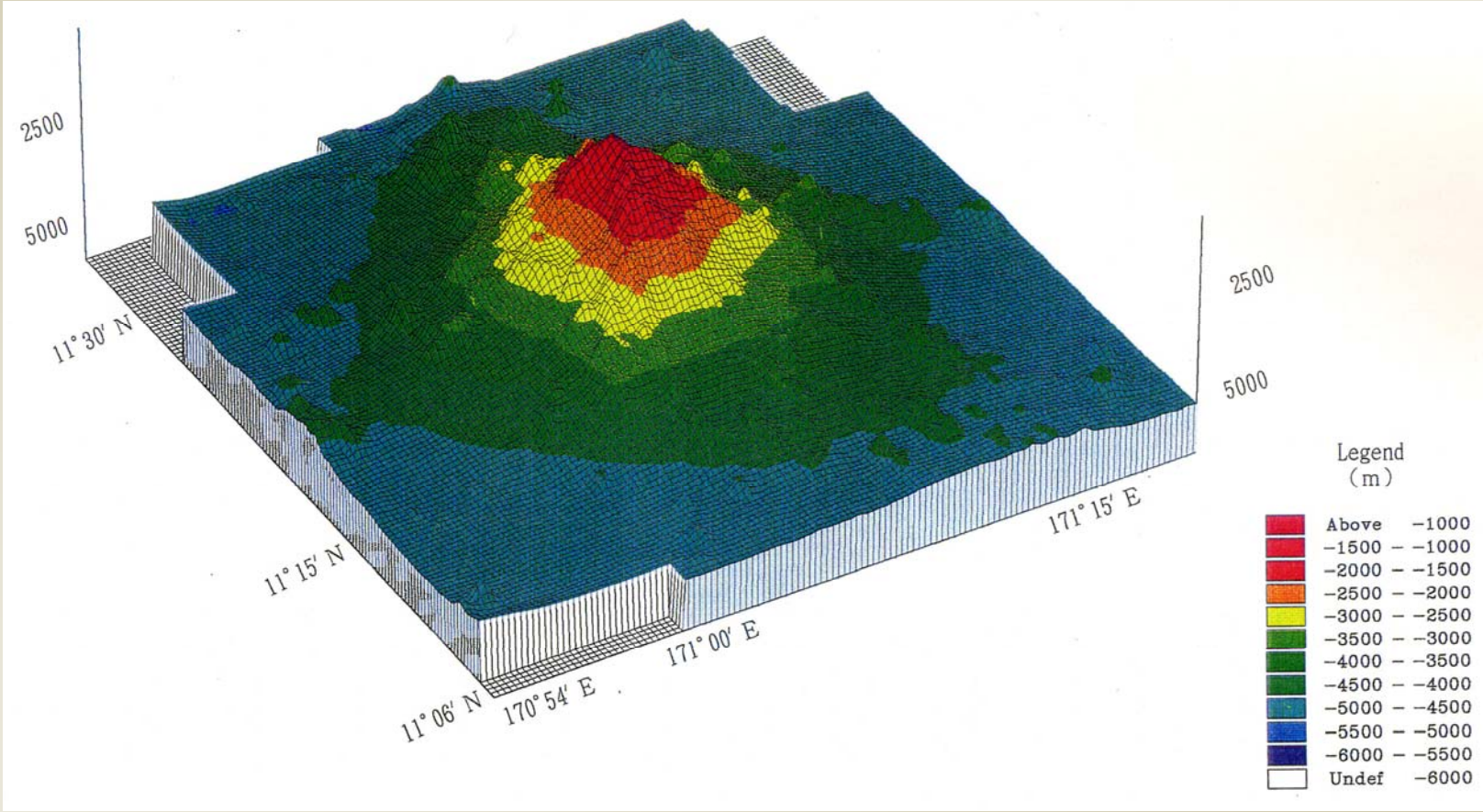
56 kilometers long
Terraces: smooth and rough
Large area above 2500 m
Debris apron

Typical Guyot

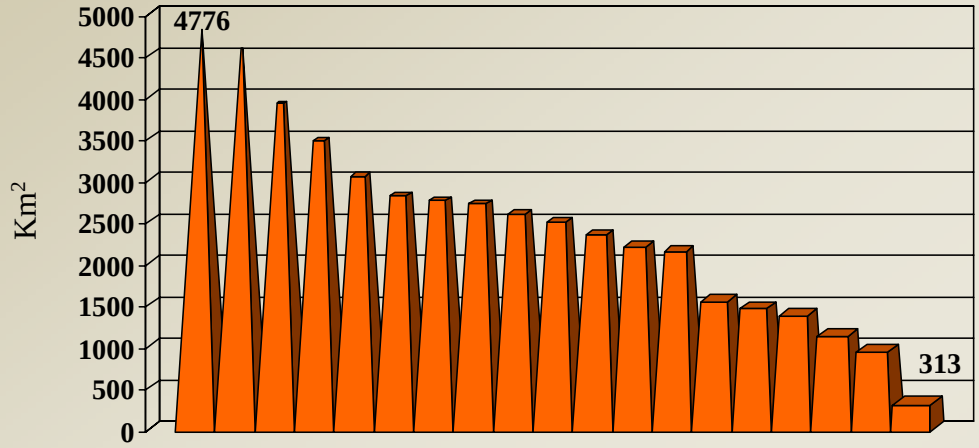


Typical Conical Seamount

14˚ slopes
Small area above 2,500 m
Rugged summit



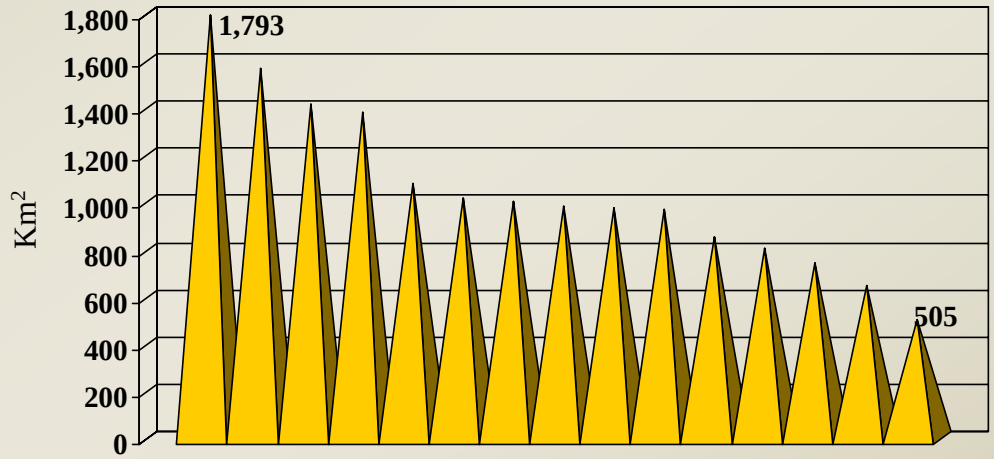
Total surface area of 19 Central Pacific Guyots



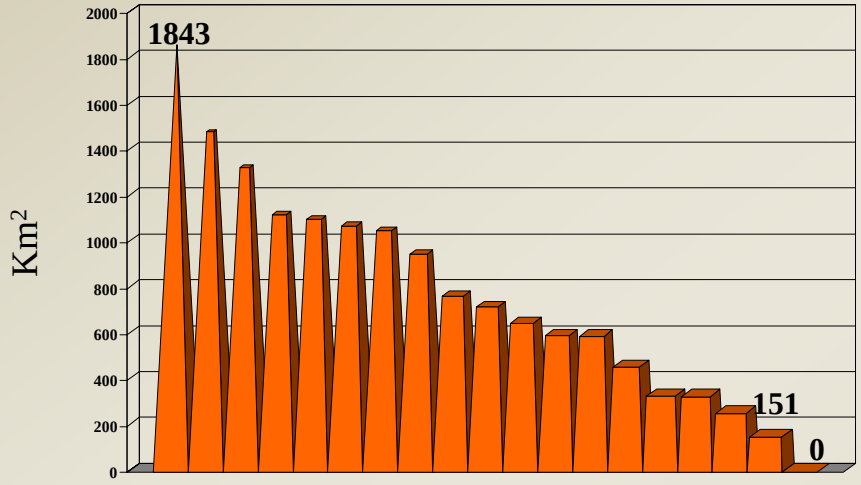
Total surface area of 34 seamounts: 62,250 km^2
Geographic area hosting 34 seamounts: 506,000 km^2

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

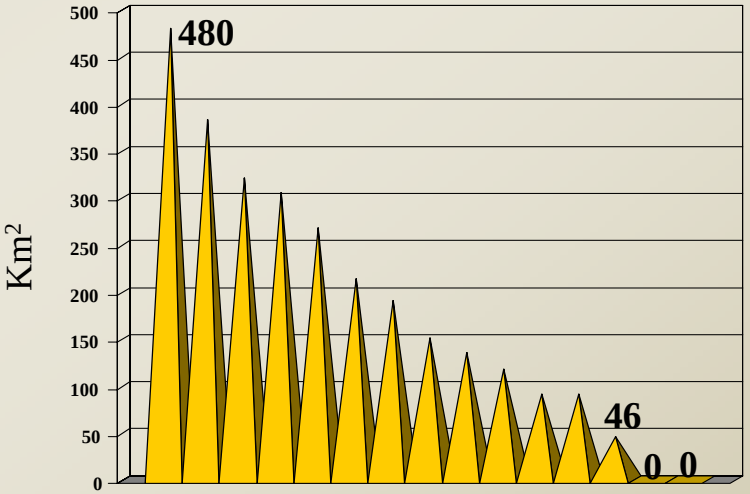
Total Surface Area of 15 Central Pacific Conical Seamounts



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 km^2

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

Average Seamount
(Surface Area Statistics for 34 Seamounts)

	Total Surface Area (km^2)	*Surface Area above 2500m water depth (km^2)*
Mean	1,850	515
Median	1,450	325
SD[1]	1,150	470
Minimum	310	0
Maximum	4,775	1,843

[1] Standard Deviation

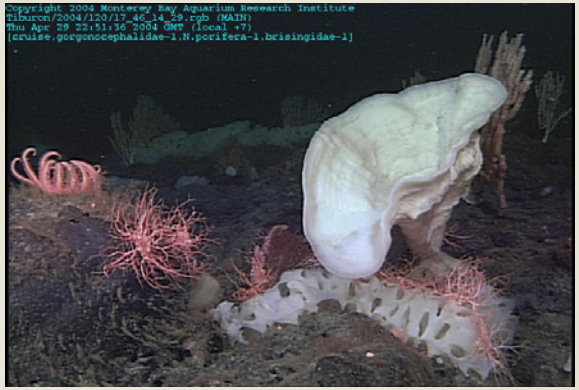
25 km^2/yr mining area
500 km^2/20 yrs mining area
2,500 km^2 for exploration for mine sites

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 km^2 for largest seamount in data set (1,254 km^2 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

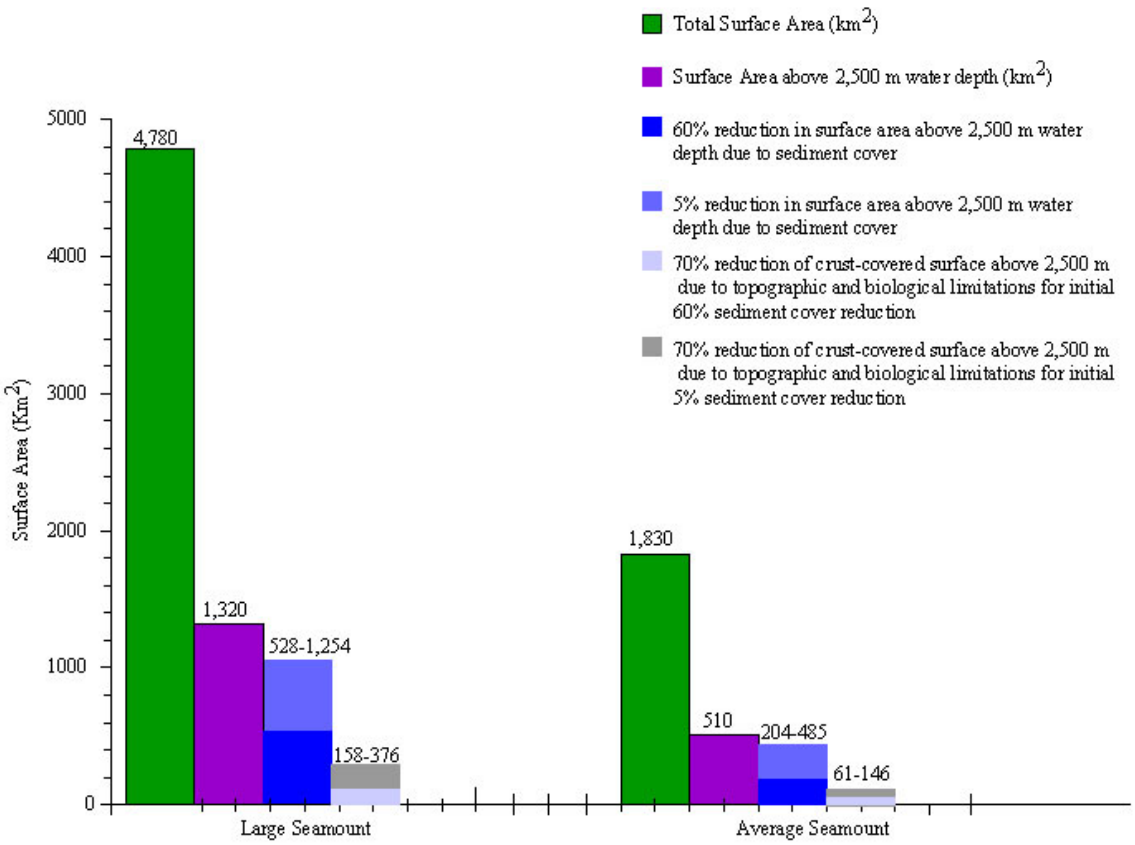
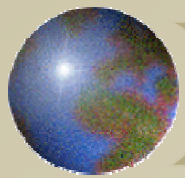


Figure 2. Surface area available for potential mine sites considering worst-case (60% sediment cover) and best-case (5% sediment cover) scenarios.



Crust thickness and square meter tonnage

- Worst case: mean crust thickness of 2 cm = 39 kg/m^2 wet weight (density 1.95 g/cm^3)
- Best case: mean crust thickness of 6 cm = 117 kg/m^2
- Model mine site: 2.5 cm net thickness = 48.75 kg/m^2
- Areas have been found with a mean crust thickness of 14 cm = an incredible 273 kg of Co-rich crusts per m^2 of seabed

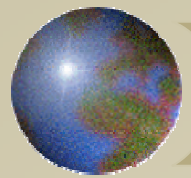
Number of seamounts

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 km^2
- The 100 km^2 blocks are composed of contiguous 20 km^2 sub-blocks
- 100 km^2 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

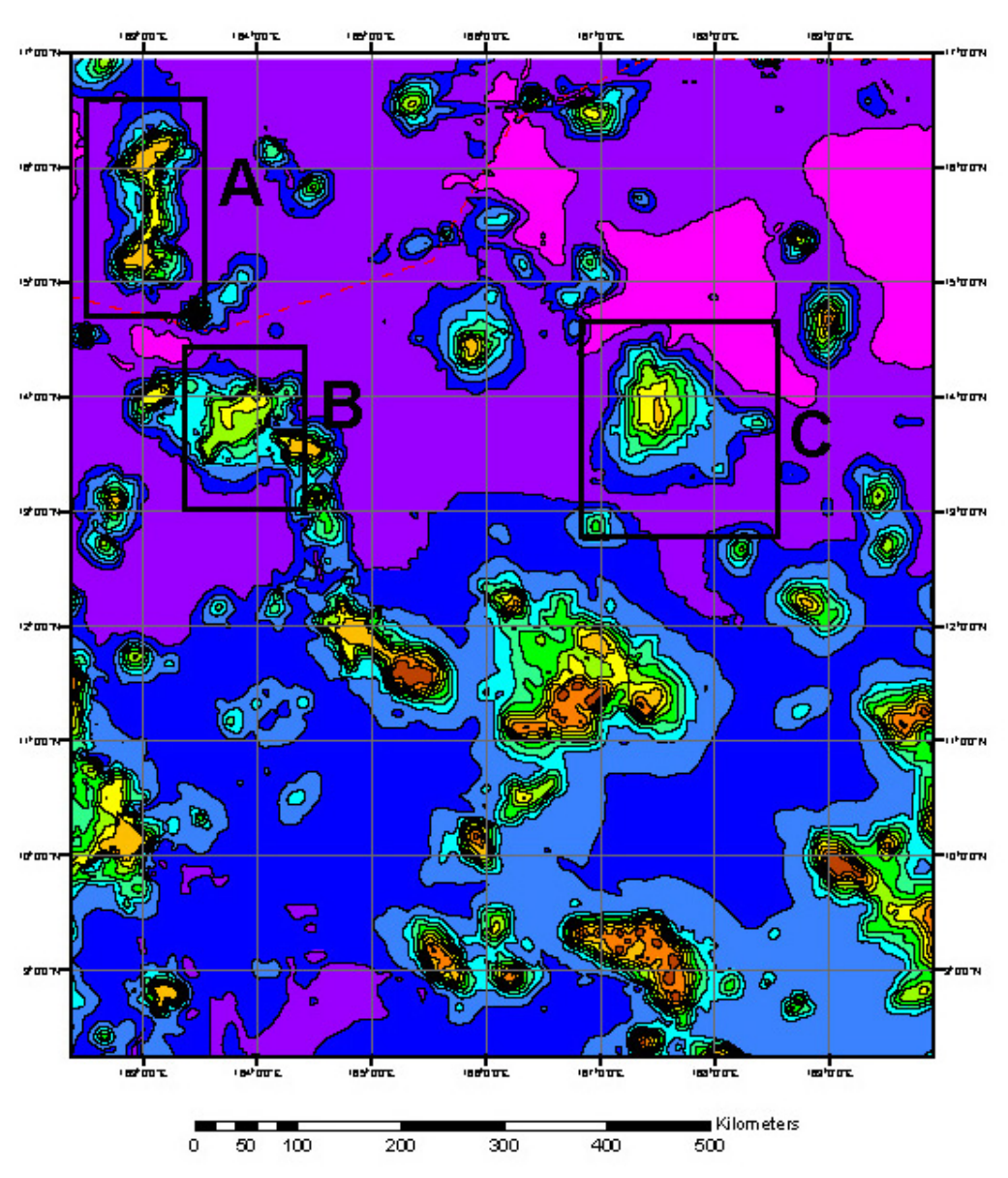
- Twenty-five 100 km^2 blocks leased for exploration
- Yielding 2,500 km^2 per exploration license
- Groups of 20 km^2 blocks relinquished during several phases
- 25 sub-blocks of 20 km^2 will define the final 20-year mine site of 500 km^2

Mine Site Parameters

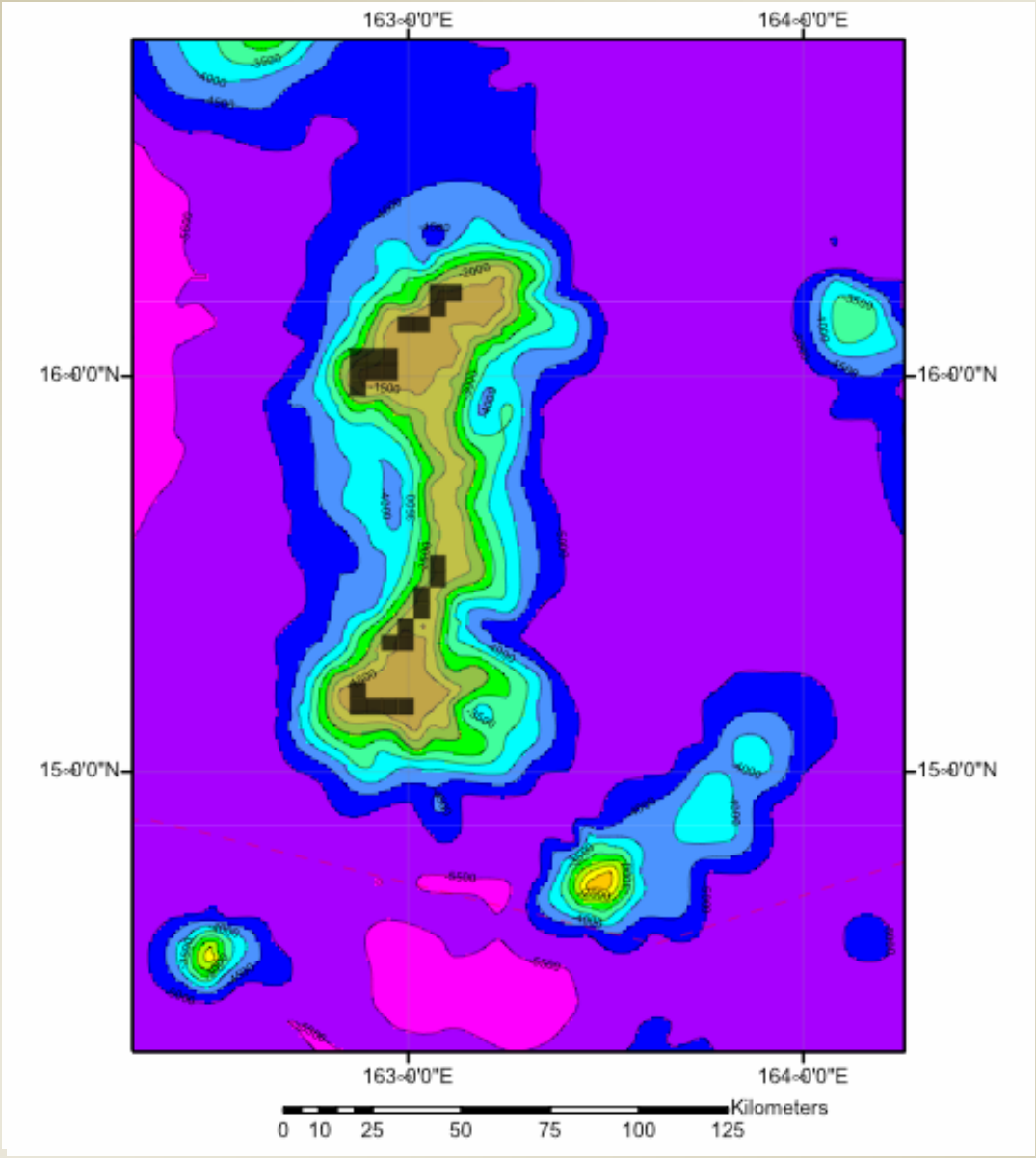
	Range	Model Site
Seamount area (km^2)	>400	>600
Seamount slope (^{o})	0-25	0-5
Water depth (m)	<2500	<2500
Mean crust thickness (cm)	2-6	2.5
Sediment cover (%)	5-60	30
Crust recovery (%)	70-90	82
Mine block size (km^2)	10-40	20
Exploration block size (km^2)	100-200	100

Area Mined

	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 (10^6 tons)	2	1	1
Area mined/year (km^2)	51.3	8.55	20.5
Recovery efficiency (%)	70	90	82
Area mined/year (km^2)	73.26	9.50	25.0
Area mined in 20 years (km^2)	1465	190	500
Area for exploration (km^2)	7326	950	2500

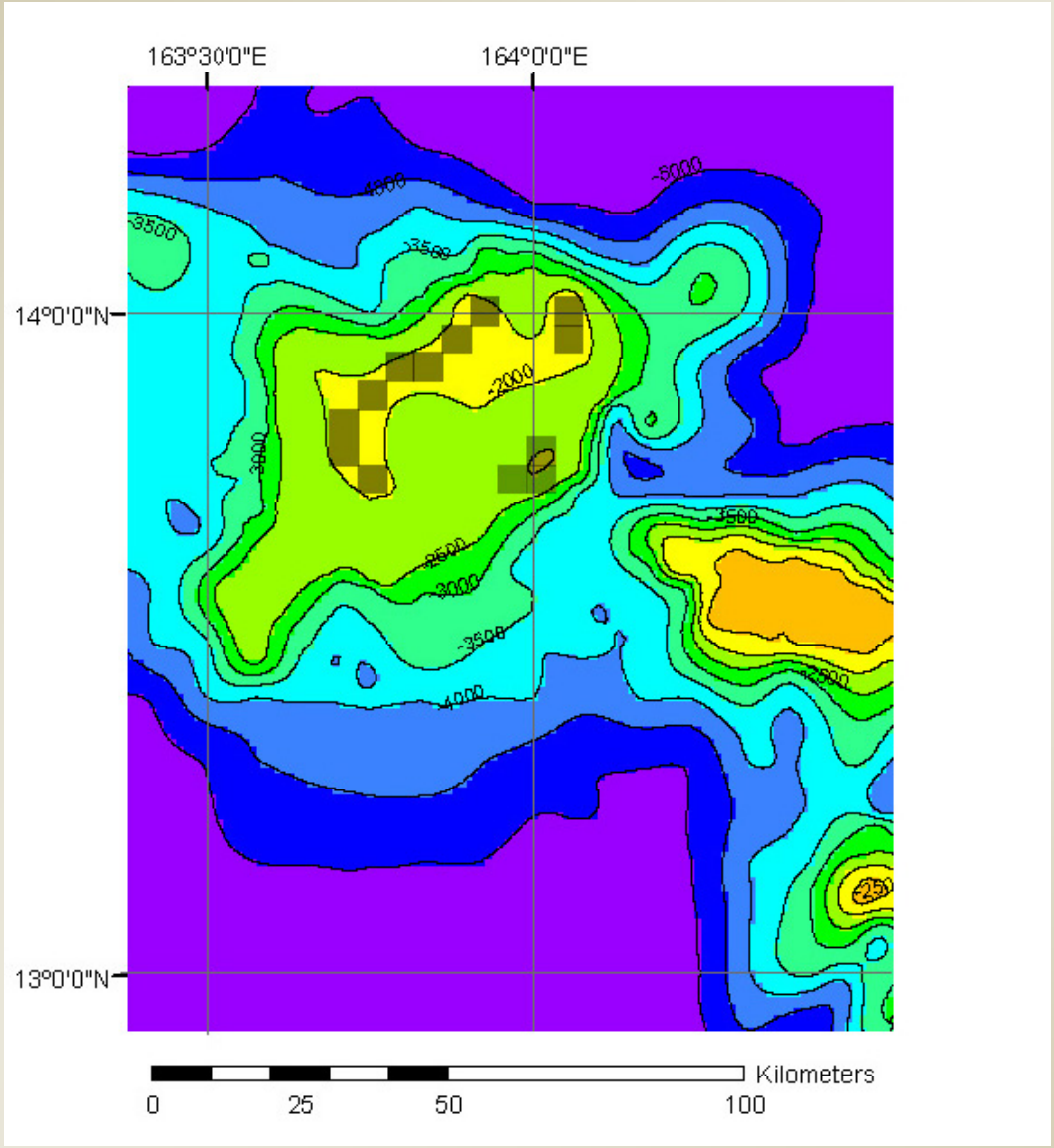


Model Mine Sites



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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164°0'0"E
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13°0'0"N
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-2500
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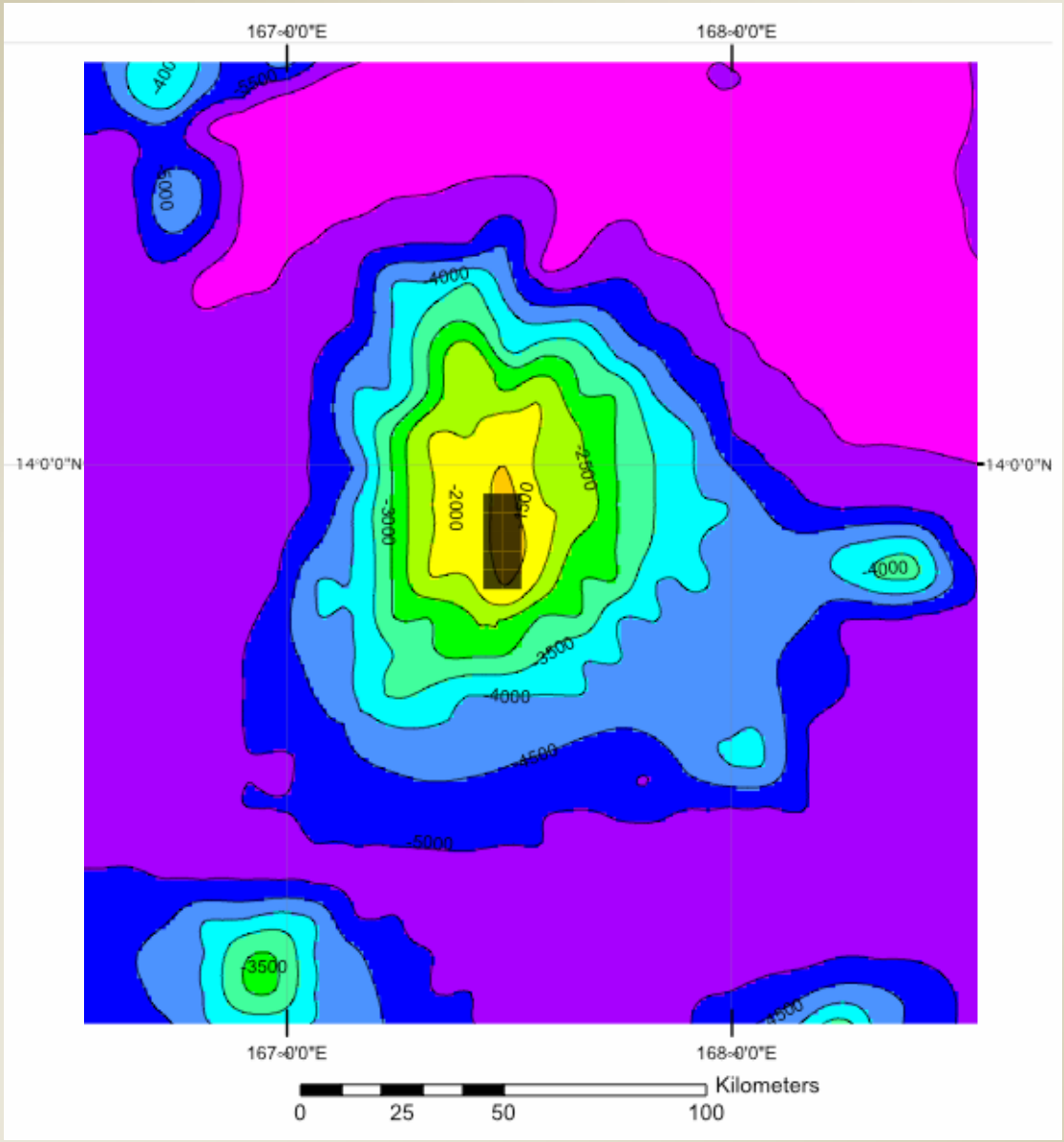
Kilometers
0
25
50
100

Seamount B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Kilometers
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Seamount C