Global Exploration Models for Polymetallic Sulphide Deposits in the Area: Possible Criteria for Lease Block Selection under the Draft Regulations on Prospecting and Exploration for Polymetallic Sulphides

Prepared for the International Seabed Authority by
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June 21, 2006

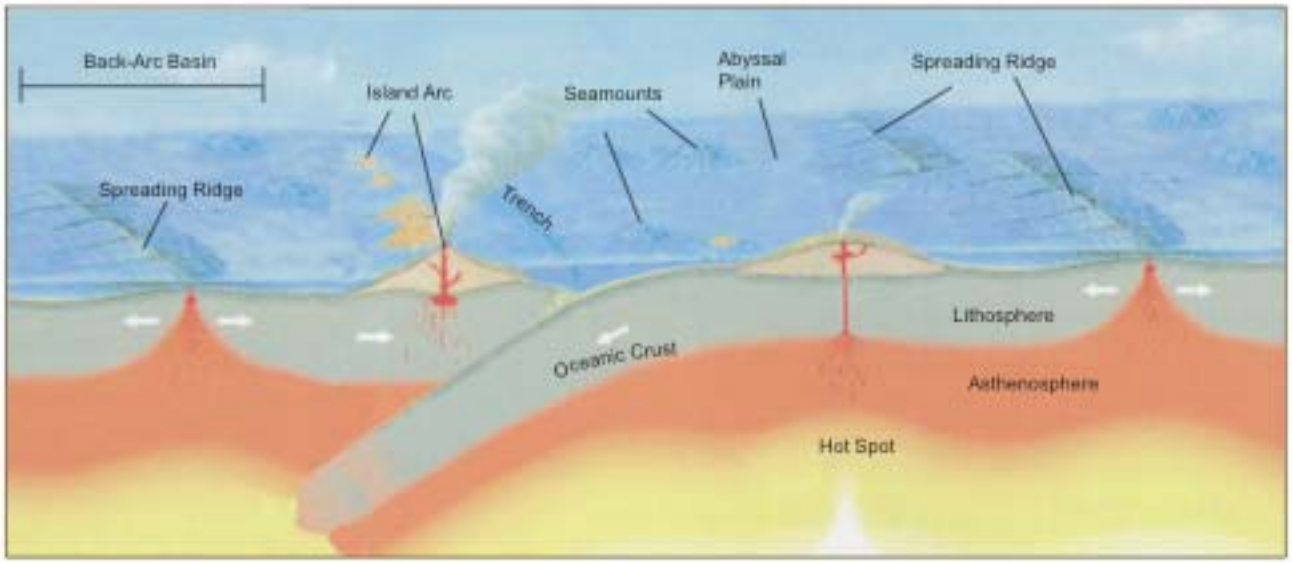
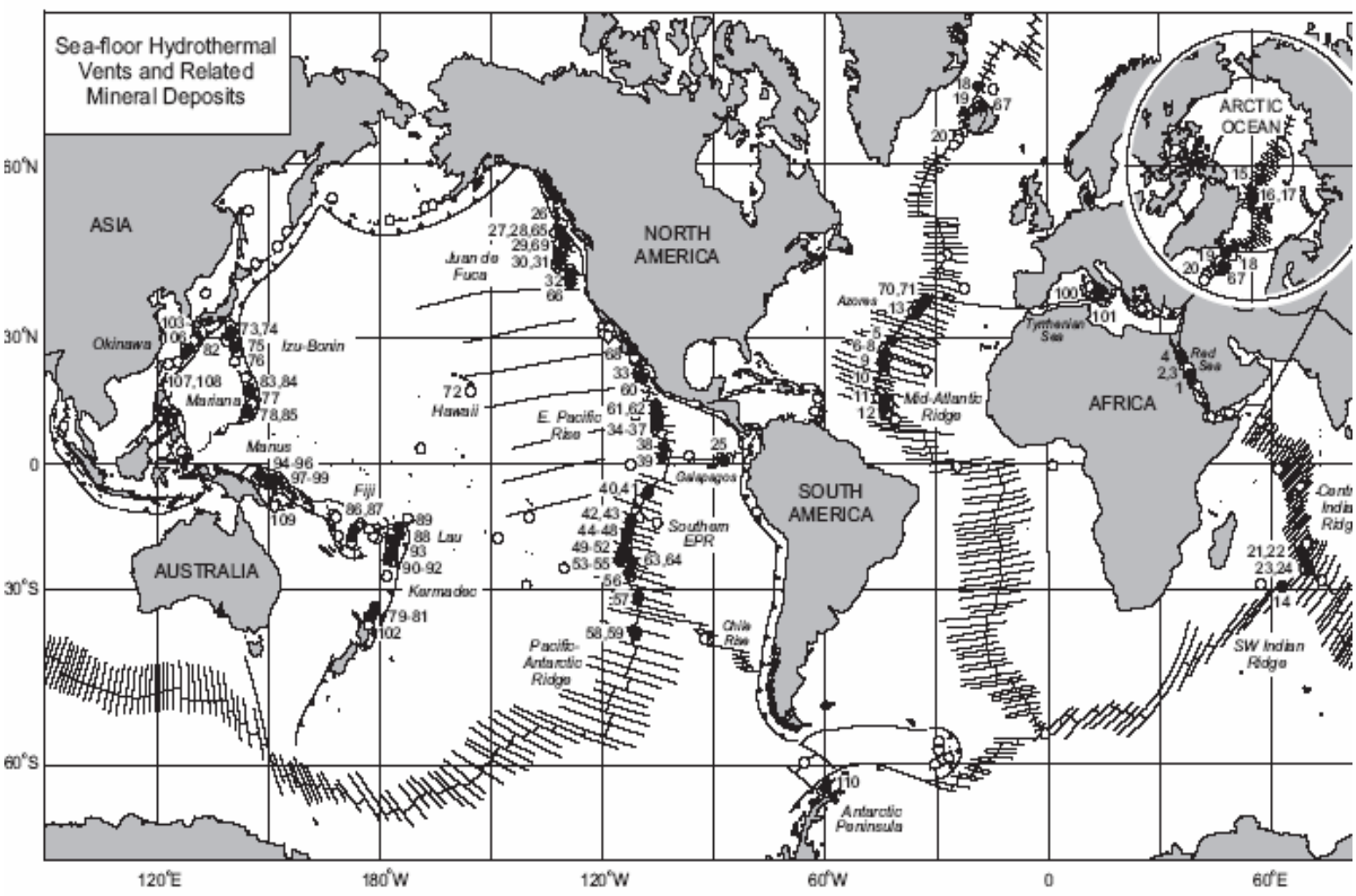
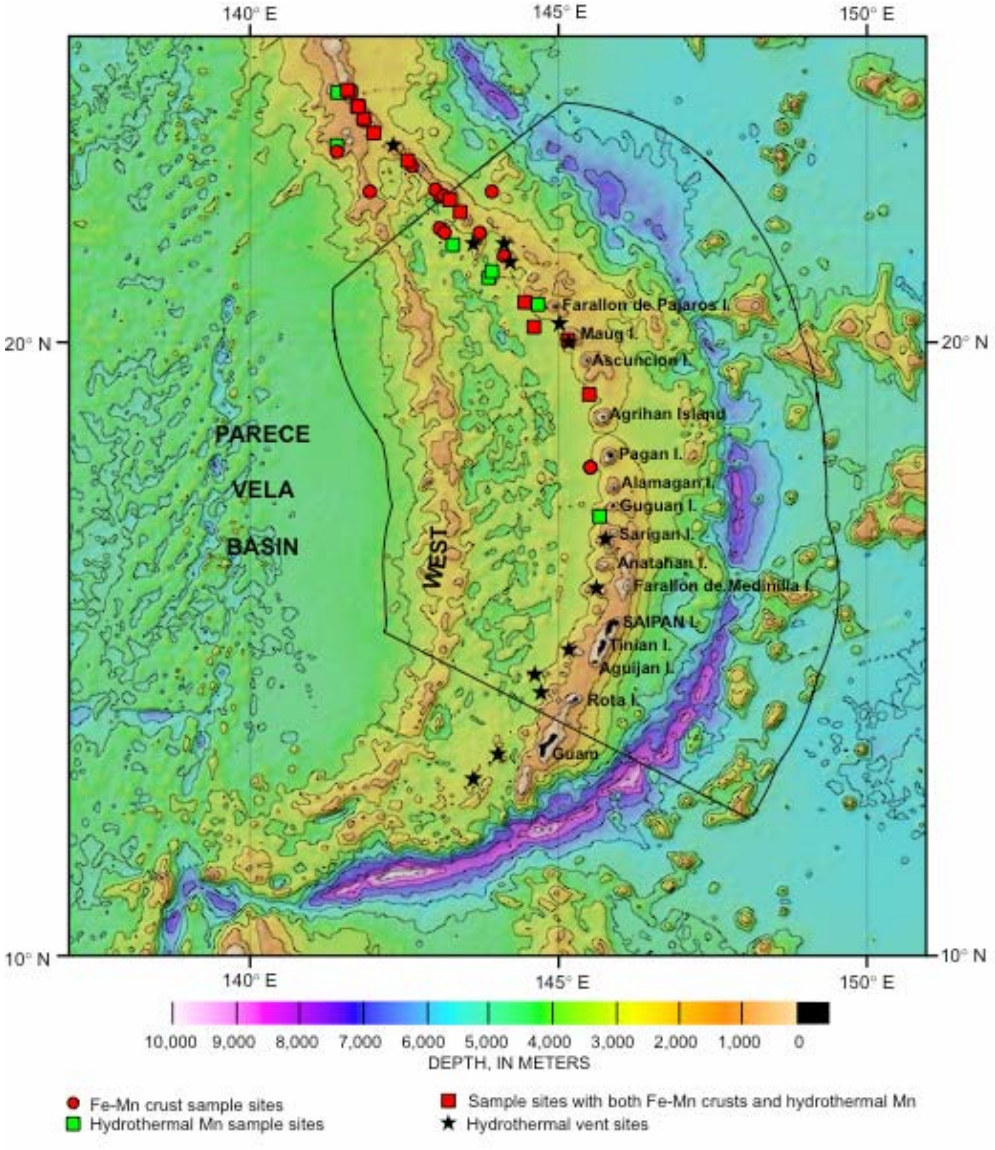


Figure 2. Schematic diagram of oceanic, tectonic, and physiographic settings where deep-sea mineral deposits form. Hydrothermal mineral deposits form along oceanic and back-arc-basin spreading ridges, along island arcs, and at hot-spot volcanoes. Ferromanganese crusts form on the flanks of seamounts and islands, and ferromanganese nodules form on the abyssal sea floor (modified from Jose F. Vigil's illustration in This Dynamic Planet, a wall map published in 1994 jointly by the USGS, Smithsonian Institution, and the U.S. Naval Research Laboratory).


Sea-floor Hydrothermal Vents and Related Mineral Deposits
ASIA
NORTH AMERICA
SOUTH AMERICA
AFRICA
AUSTRALIA
ARCTIC OCEAN
Juan de Fuca
Okinawa
Izu-Bonin
Mariana
Manus
Fiji
Lau
Kermadec
Hawaii
E. Pacific Rise
Galapagos
Southern EPR
Chile Rise
Pacific-Antarctic Ridge
Antarctic Peninsula
Azores
Mid-Atlantic Ridge
Tyrrhenian Sea
Red Sea
SW Indian Ridge
60°N
30°N
0
30°S
60°S
120°E
180°W
120°W
60°W
0
60°E


140° E
145° E
150° E
20° N
10° N
PARECE
VELA
BASIN
WEST
Farallon de Pajaros I.
Maug I.
Ascuncion I.
Agrihan Island
Pagan I.
Alamagan I.
Guguan I.
Sarigan I.
Anatahan I.
Farallon de Medinilla I.
SAIPAN I.
Tinian I.
Aguijan I.
Rota I.
Guam
10,000 9,000 8,000 7,000 6,000 5,000 4,000 3,000 2,000 1,000 0
DEPTH, IN METERS
Fe-Mn crust sample sites
Hydrothermal Mn sample sites
Sample sites with both Fe-Mn crusts and hydrothermal Mn
Hydrothermal vent sites

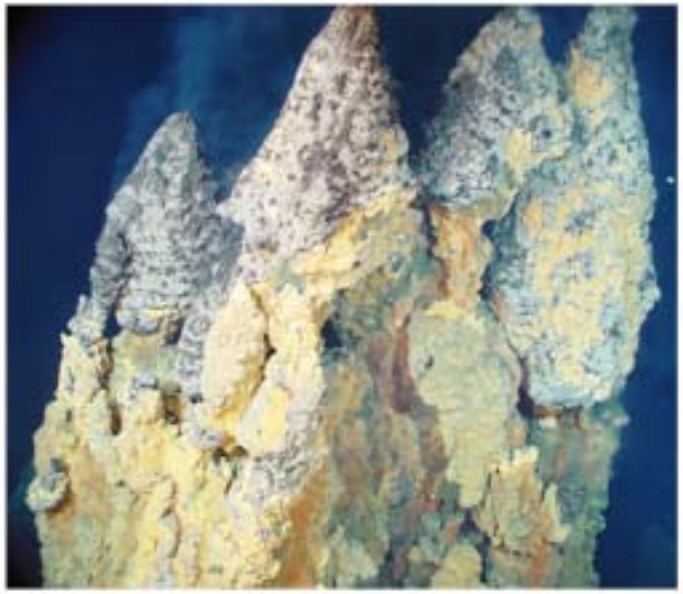


Figure 5. A group of active sulfide chimneys from the Northern Mariana Islands EEZ; note the gray particulate matter above and to the right of the group of chimneys, which originates from the orifice of each individual chimney. Water depth is 345 meters. (http://oceanexplorer.noaa.gov/explorations/04fire/)

Distribution of polymetallic sulfides

- More than 300 hydrothermal venting sites
- 40% of those are in The Area
- 65% at mid-ocean ridges; 22% back-arc basins; 12% volcanic arcs; 1% mid-plate volcanoes
- 100 of those host polymetallic sulfides
- 55,000 km of oceanic spreading ridge; 22,000 km of volcanic arc and back-arc spreading
- Only 2 known to be greater than 1 million tons; 5 others may also contain >1 million tons
- Individual occurrences cover no more than 1 km diameter
- Median tonnage in most 100 km^2 blocks will not be greater than 50,000 tons (analogs)

Vent site characteristics

- Average spacing is 98 km; 167 km for slow-spreading ridges; 46 km for fast-spreading ridges
- Based on heat flux considerations, about 1 vent field every 50-100 km along ridge
- Individual vent fields are 10s to 100s m in diameter and may be separated from adjacent vent fields by 100s to1000s m
- Example: Endeavour segment of Juan de Fuca Ridge consists of 30 different sulfide complexes distributed among 8 vent fields along a 10 km segment of the axial valley; the main vent fields are 2-3 km apart.
- TAG mound is 200 m x 60 m, 2.7 million tons 2% Cu

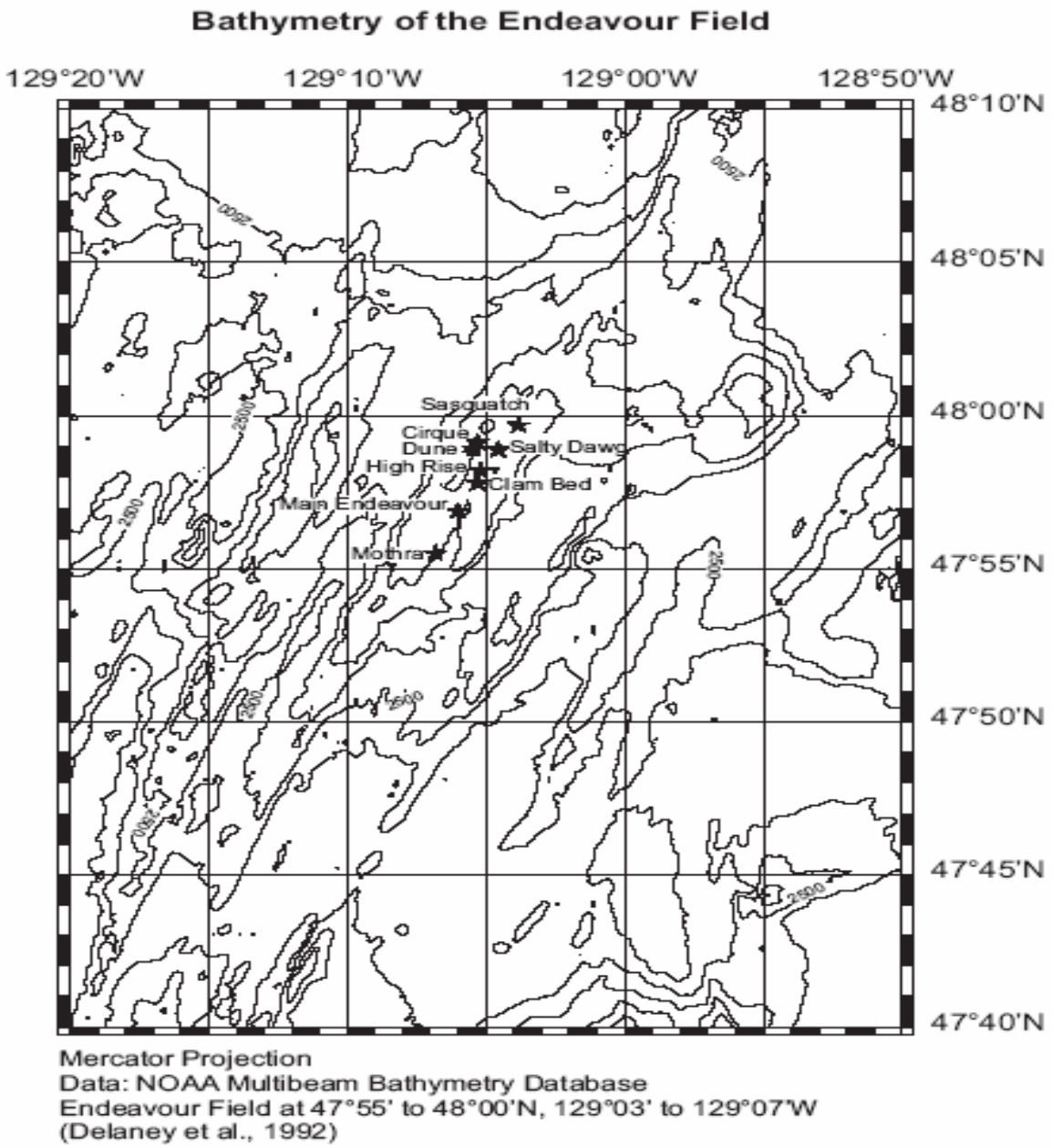


Figure A2. 30 min by 30 min map of the Endeavour Ridge (100 m contour interval) showing the locations of discrete sulfide occurrences, located about 2-3 km apart.

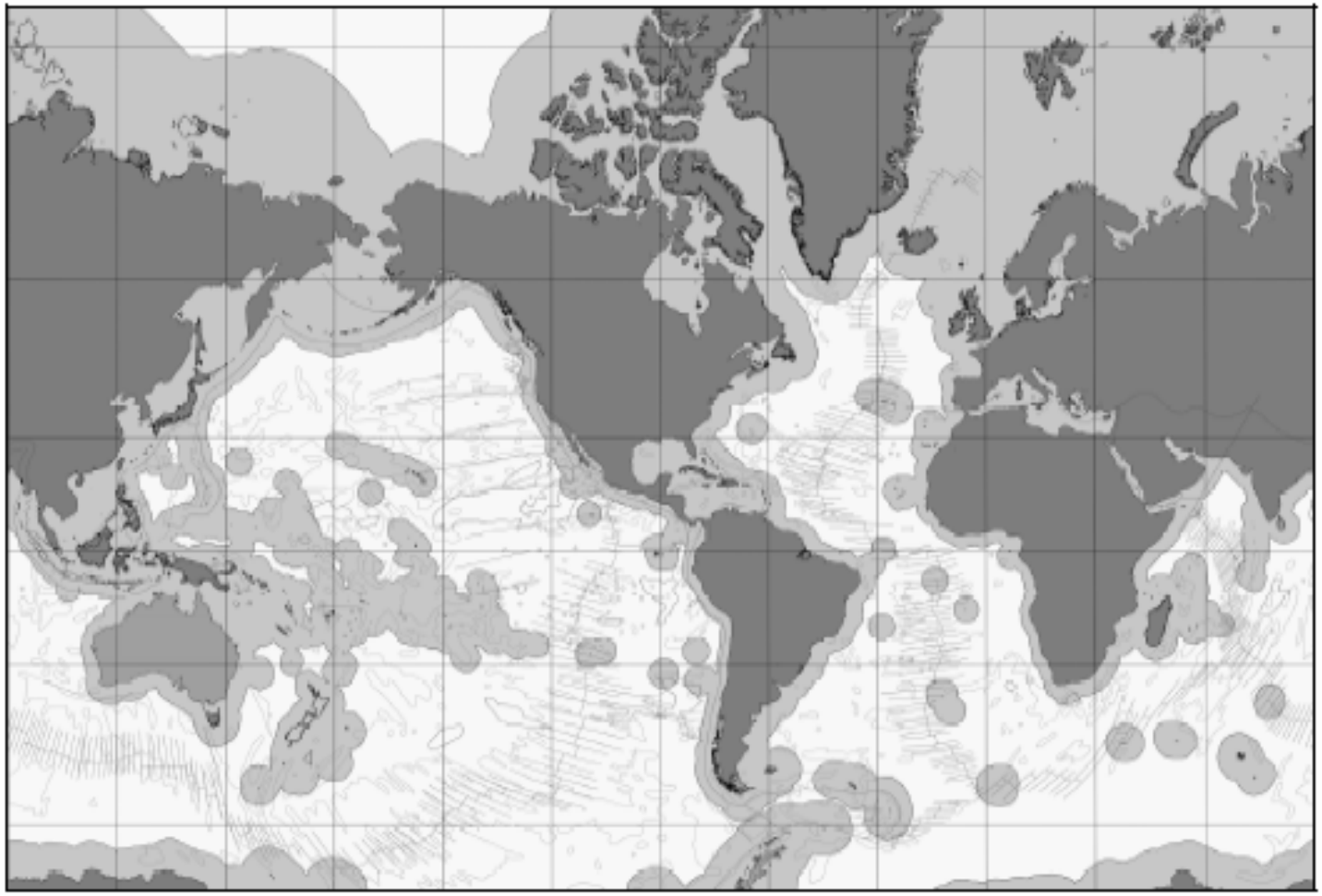


Figure 2. Distribution of seafloor hydrothermal vents and occurrences of seafloor polymetallic sulfides (Hannington et al., 2005). Numbers refer to occurrences listed in Table 1. Other low-temperature hydrothermal vents and Fe-Mn crusts or metalliferous sediments are indicated by open circles. Major spreading ridges and subduction zones (volcanic arcs and back-arcs) are indicated.

Terminology

- Prospecting area: arbitrarily defined as 5 degree by 5 degree areas (~308,000 km^2); 32 such areas analyzed
- Permissive area: A portion of a prospecting area having a number of geological attributes that are considered to be essential for the formation of polymetallic sulfides (~500 blocks = 50,000 km^2)
- Exploration area consists of one hundred 100 km^2 blocks = 10,000 km^2
- Lease block is 10 x 10 km = 100 km^2
- Final lease is 25 blocks = 2,500 km^2

Permissive areas, number of known sulfide occurrences, and spacing between occurrences in 12 areas (5 by 5 deg)

in The Area

	Permissive area (sq km)	Number of occurrences in area	Max # Occur in 100 C-bl	Max # in final 25 blocks	Av spacing (km)
EPR	80,000	8	6	3	54
EPR	50,000	4	4	3	23
EPR	50,000	1	1	1	--
EPR	40,000	2	2	2	10
ERP	60,000	4	3	2	120
EPR	60,000	9	6	3	55
EPR	50,000	2	2	2	15
MAR	50,000	2	1	1	300
MAR	45,000	2	1	1	175
MAR	60,000	3	2	2	87
MAR	60,000	2	2	2	--
CIR	50,000	5	3	2	108

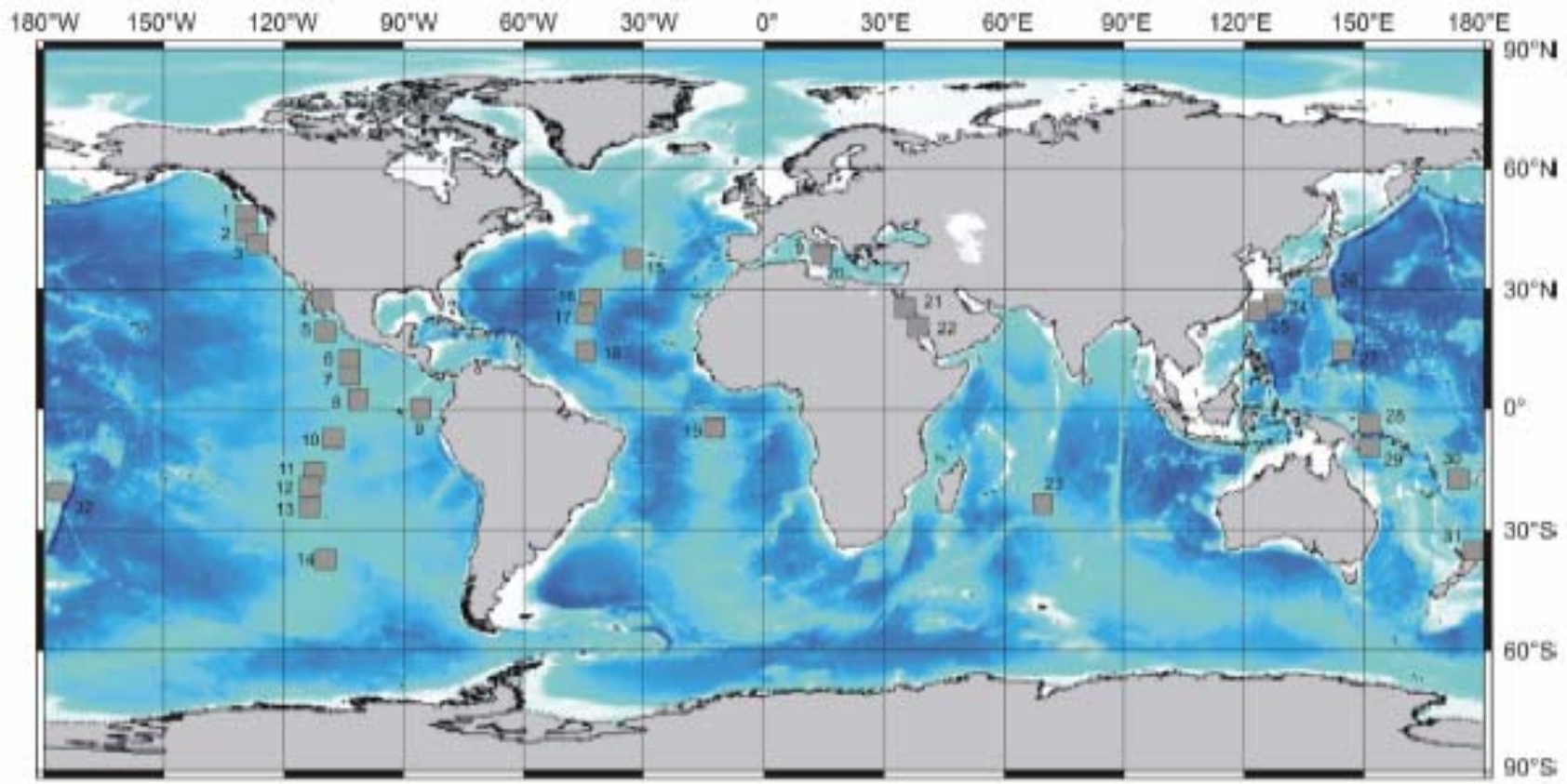


Figure 3. Locations of national EEZs (shaded areas correspond approximately to the 200 nm limit). The distribution of mid-ocean ridges in "the Area" is also shown.

Two Models Analyzed

- Exploration model 1: all blocks are contiguous
- Average of 2.5 occurrences in each 10,000 km^2
- Encompasses 73% of known sulfide occurrences in exploration area and only 53% in the permissive area

Model 2

- Exploration model 2: blocks are contiguous within non-contiguous clusters
  - Exploration area is split into 4 clusters of 25 blocks each
  - Final composed of 25 non-contiguous blocks
- Captures 97% of known sulfide occurrences
- Conclusion: Non-contiguous clusters of blocks are required

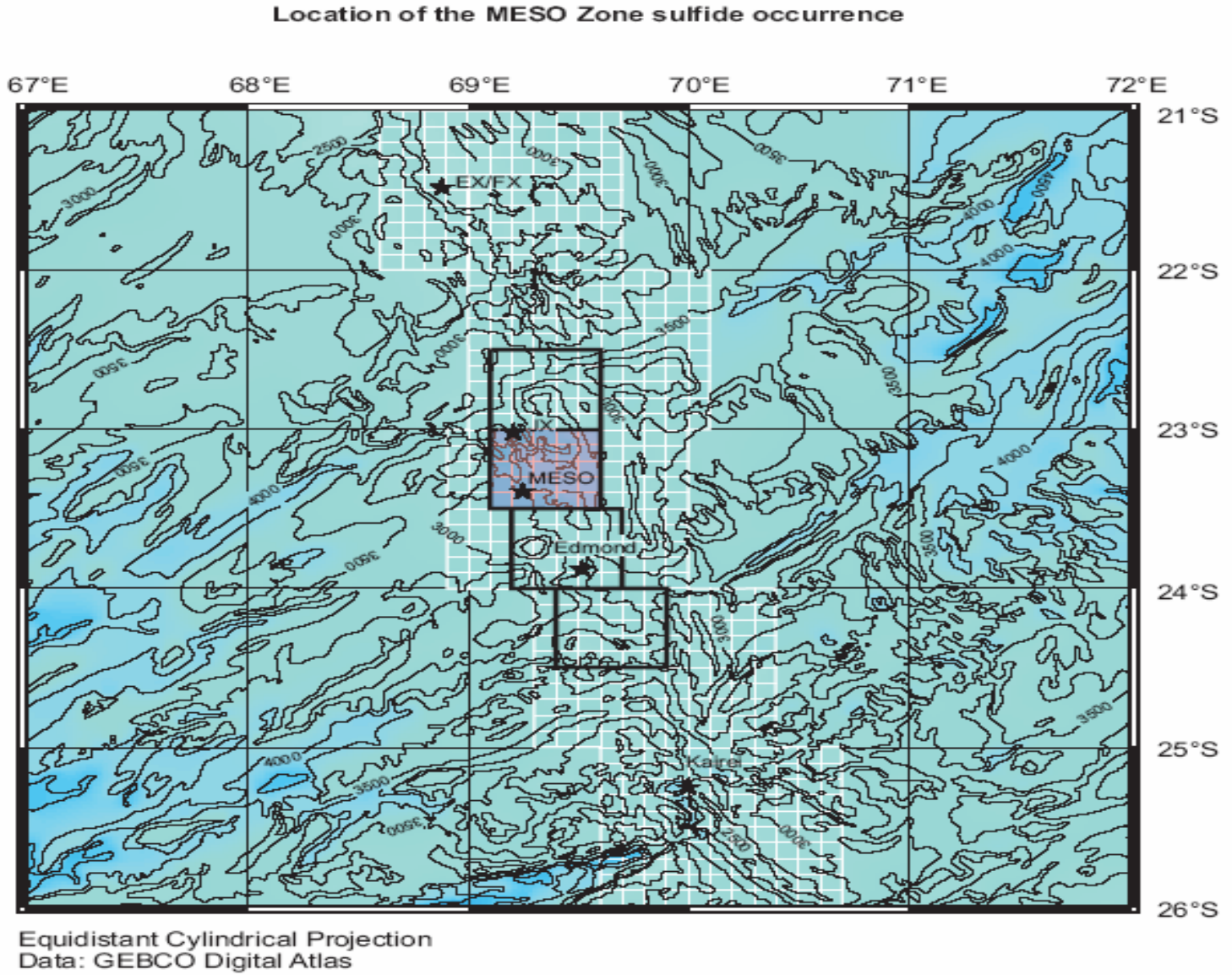


Figure 4. An application of Model 1 in the Central Indian Ridge, showing 100 contiguous blocks of 10 km x 10 km each that were leased for exploration and contain at least one known sulphide occurrence or other positive indication of mineralization in the 10,000 km sq. area. 50% of the exploration area is relinquished in the first exploration stage (5 years), leaving 50 contiguous blocks of 10 km x 10 km each, containing three of the 5 known sulphide occurrences in a 5,000 km sq. area. In the final stage of exploration, 25 contiguous blocks of 10 km x 10 km each are retained, containing two of the known sulphide occurrences in a 2,500 km sq. area. In this model, two occurrences were left outside the initial exploration area and a third occurrence had to be relinquished in order to retain only contiguous blocks in the final selection of 25.

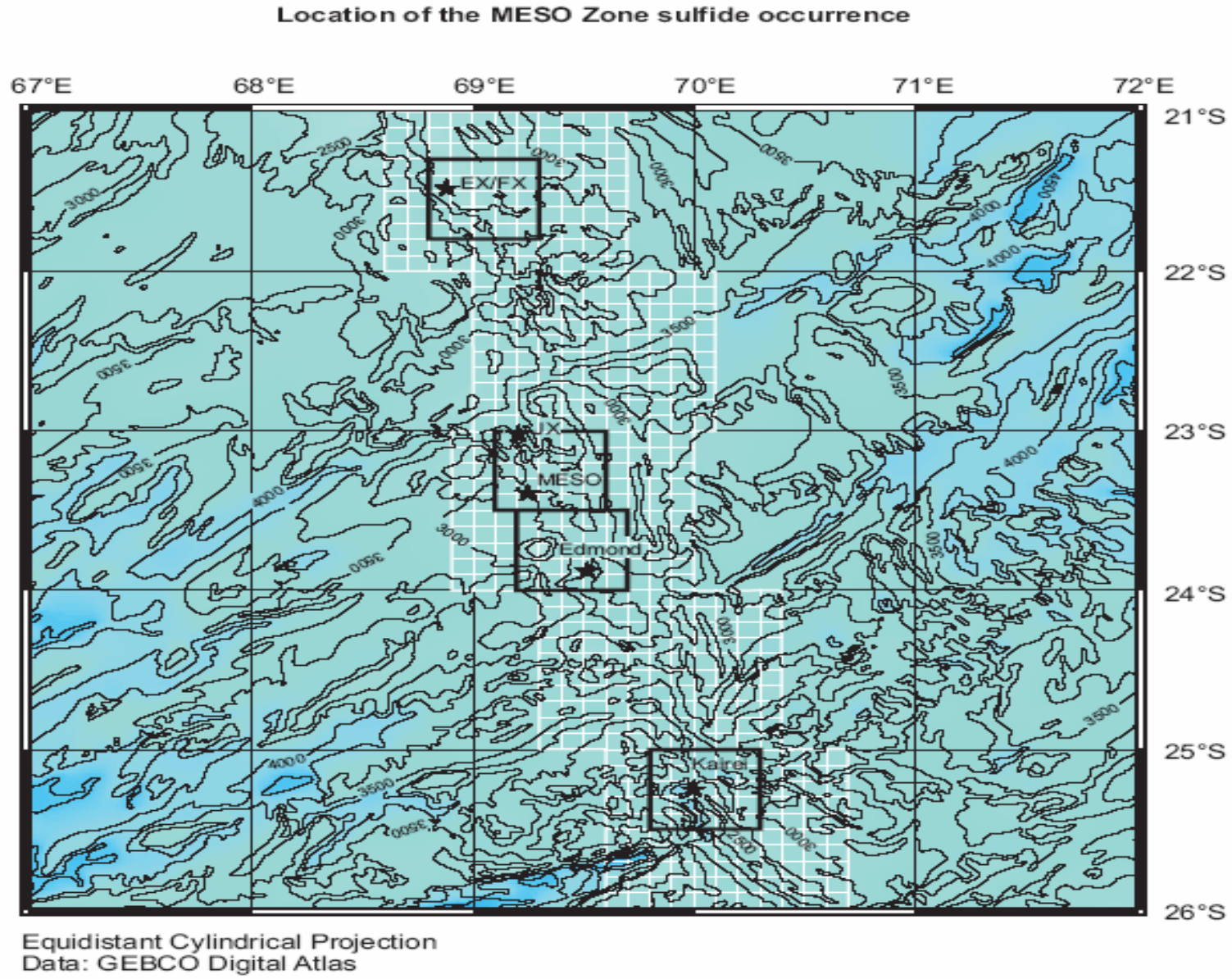


Figure 5. An application of Model 2 in the same areas as Figure 4, showing 100 non-contiguous blocks of 10 km x 10 km each, split between 4 clusters of 25 contiguous blocks of 2,500 km2 each, containing all of the known sulphide occurrences in a total combined area of 10,000 km2. There is no guarantee that the most prospective blocks would be correctly identified in the exploration phase, but it is a reasonable expectation that explorers will be able to apply appropriate criteria to maximize the selection of clusters of blocks that contain sulphides. The initial area for exploration may need to be significantly larger than 10,000 km2 in order to secure all of the sulfide occurrences in the final stage of exploration.

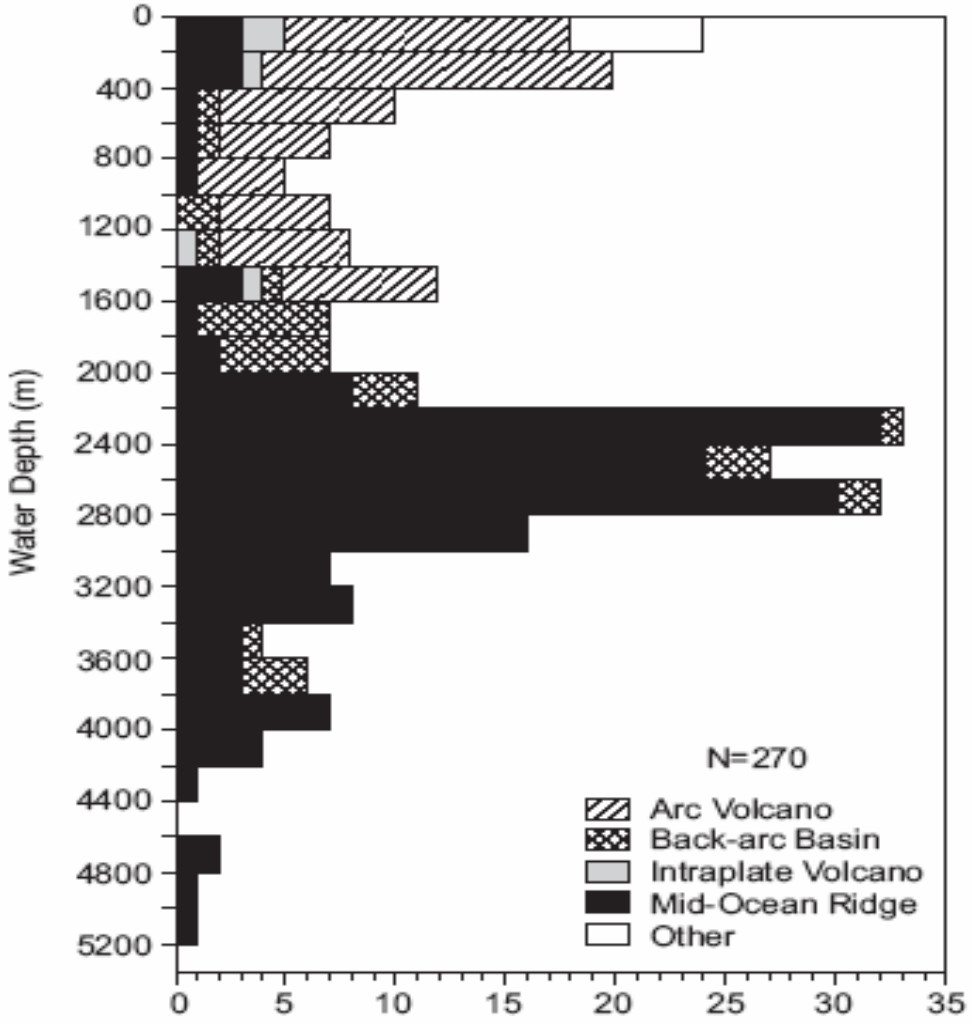


Figure 6. Depth distribution of seafloor hydrothermal vents in different volcanic and tectonic settings (from Hannington et al., 2005, modified after Massoth et al., 2003).

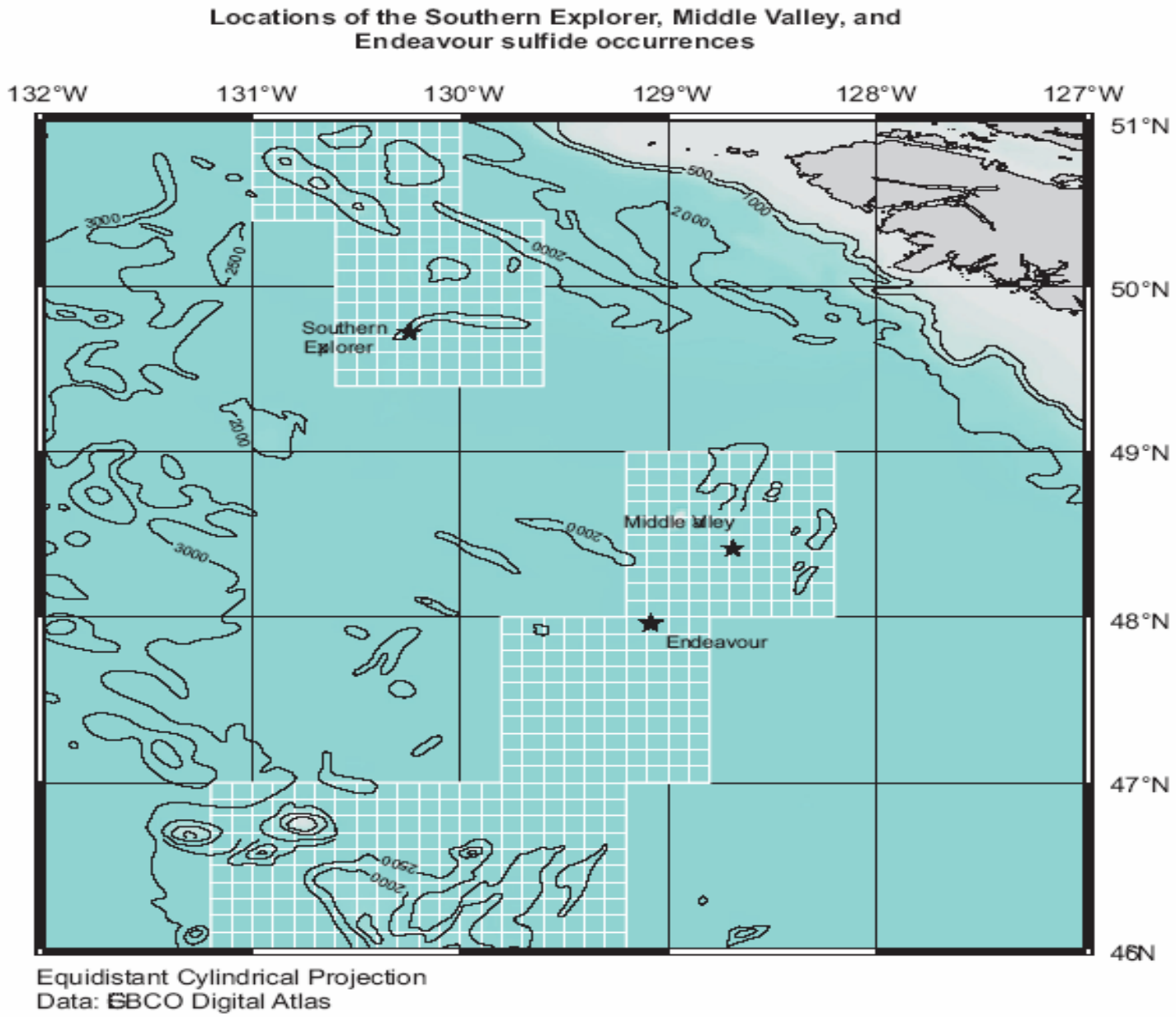


Figure A1. A. Example of a 5 degree by 5 degree area in the N.E. Pacific (1000 m contour interval), overlapping the Juan de Fuca Ridge and known occurrences of polymetallic sulfides at Southern Explorer Ridge, Middle Valley, and Endeavour Ridge.

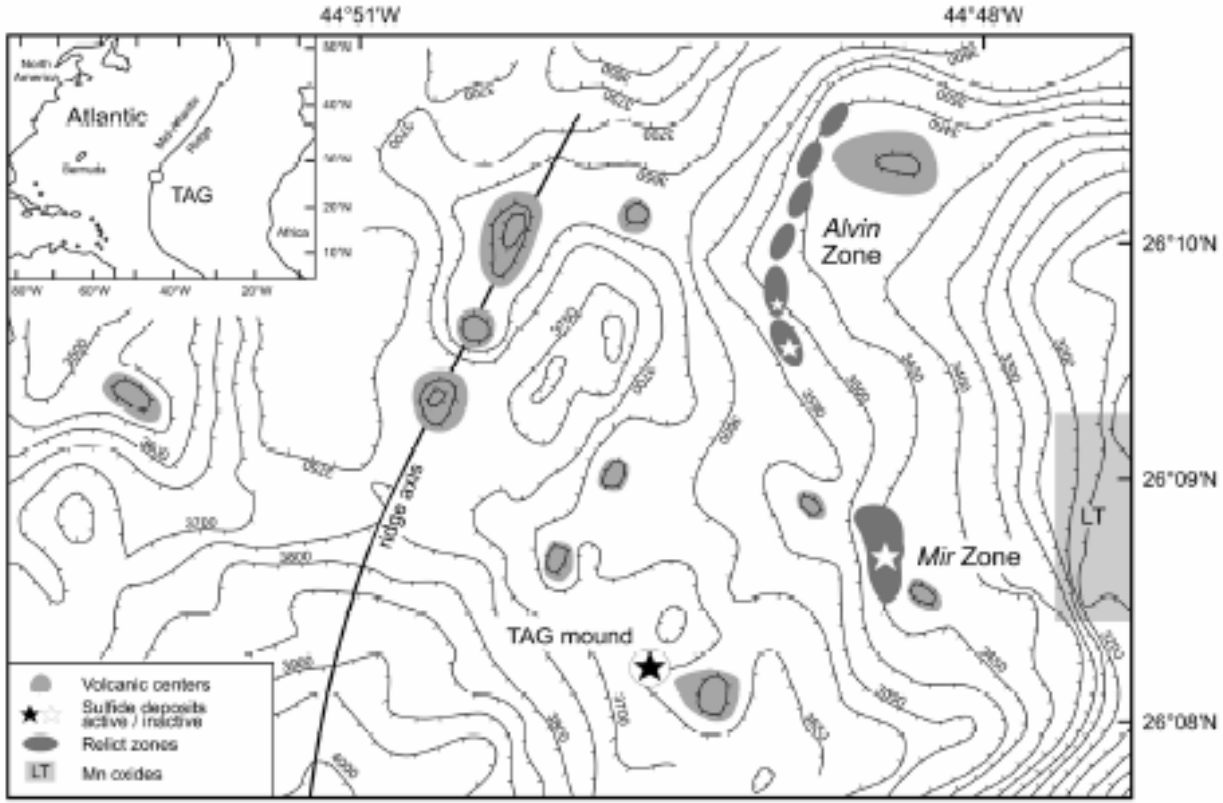


Figure A3. Distribution of sulfide occurrences in the TAG Hydrothermal Field, Mid-Atlantic Ridge (Humphris et al., 1995). The three main massive sulphide mounds (TAG, MIR, Alvin) are located within an area of about 25 km^2.

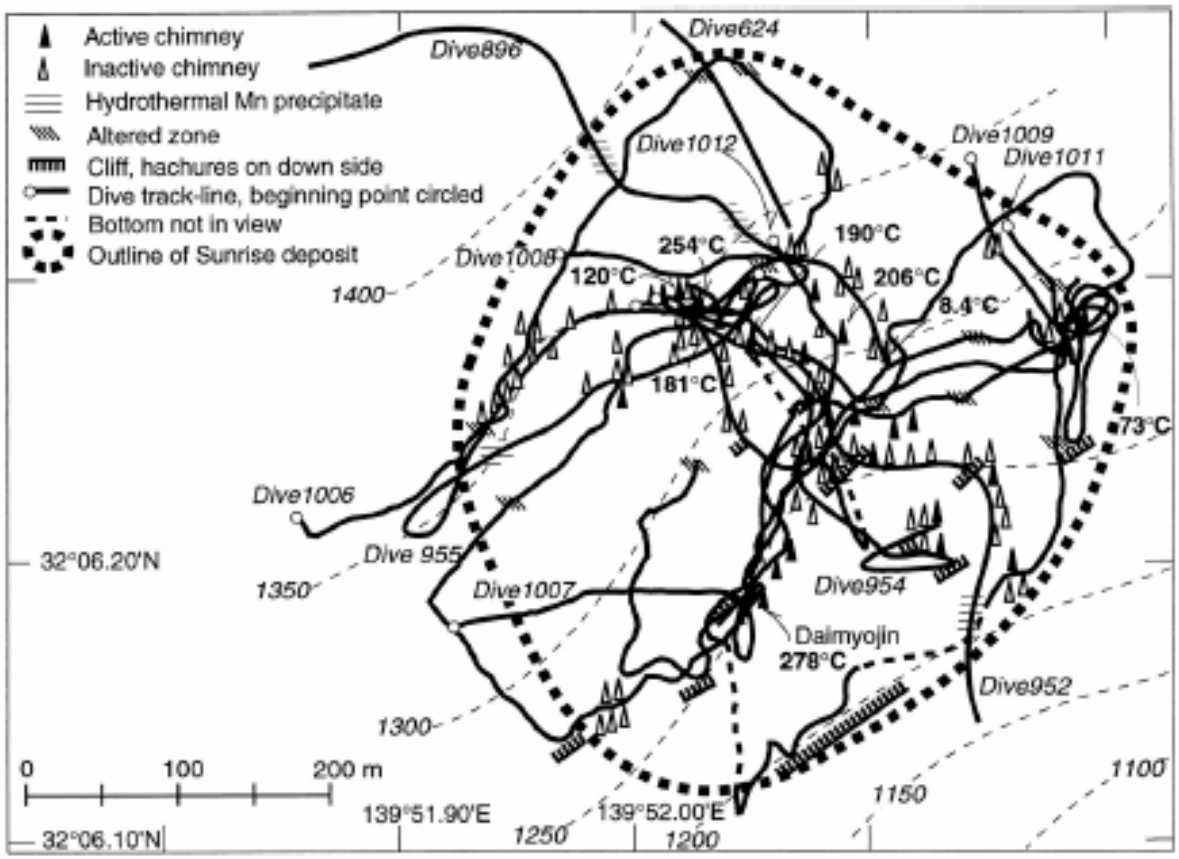


Figure A4. Map showing the submersible survey of the Sunrise occurrence, on the Myojin Knoll submarine volcano, Izu-Bonin arc (Iizasa et al., 1999). The depicted area of sulphide mineralization measures 400 m x 400 m. Based on a relief of 30 m and a bulk density of 1.9 gm/cm3, a total accumulation of 9 million tonnes of massive sulphide was calculated. However, surveys based on submersible observations or camera tows typically have a maximum field of view of not more than 10 m beyond the survey track. In the map shown, no more than 5 line-km of surveys cover the 400 m x 400 m outlined area, providing a visual coverage of not more than 30%. Visually identifiable sulphide outcrop (i.e., active or inactive sulphide chimneys) are shown to cover only about 25% of the area. Given the limitations of the visual surveys, the lack of any drilling information, and the fact that the sulfides are not deposited on a flat seafloor, the calculated tonnage is uncertain.

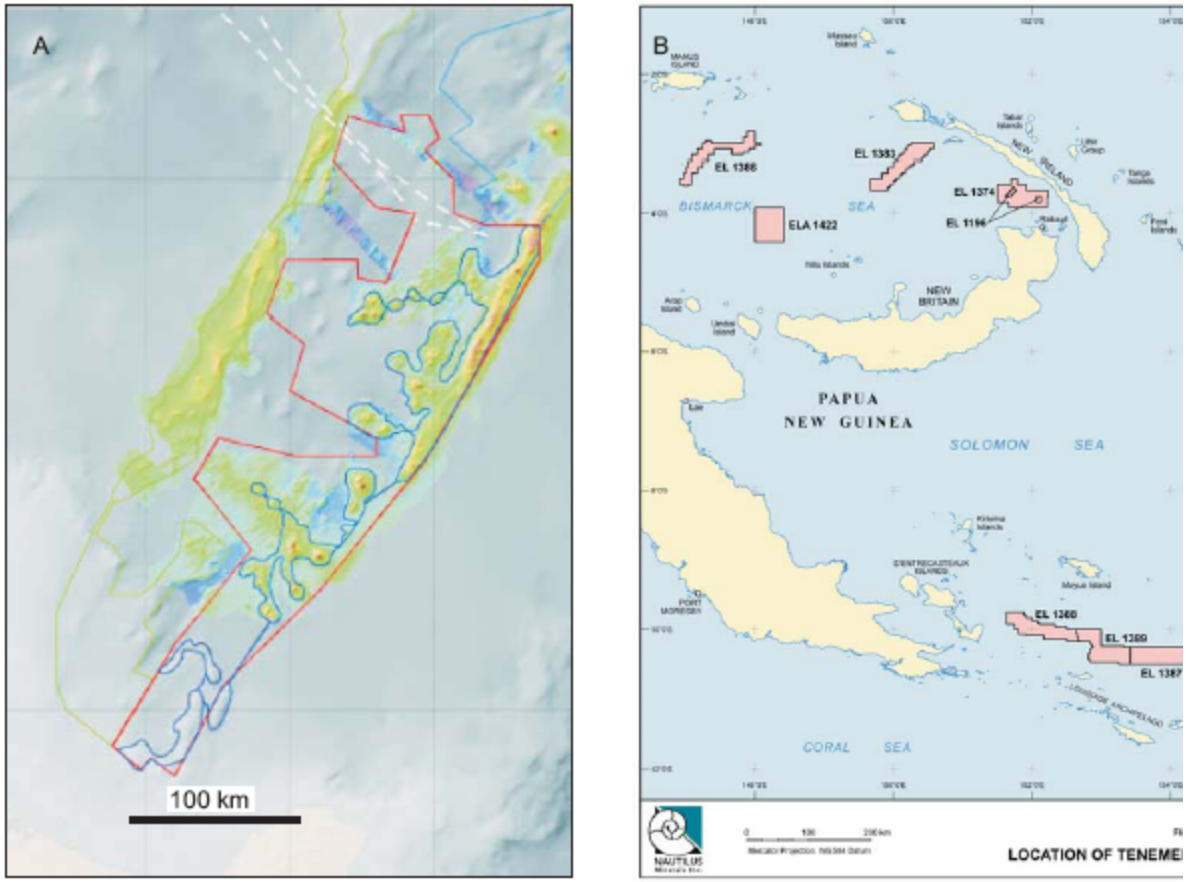
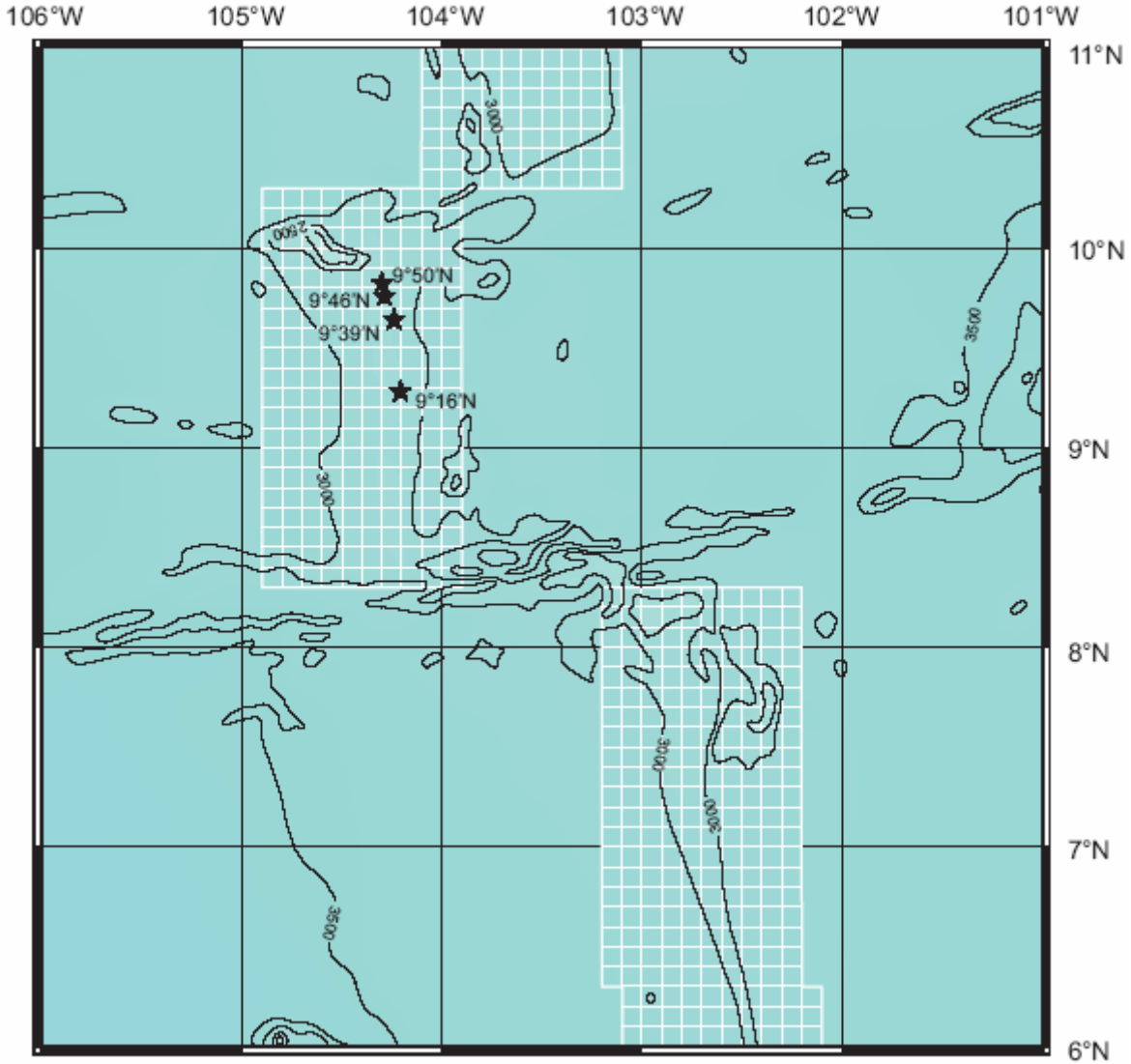
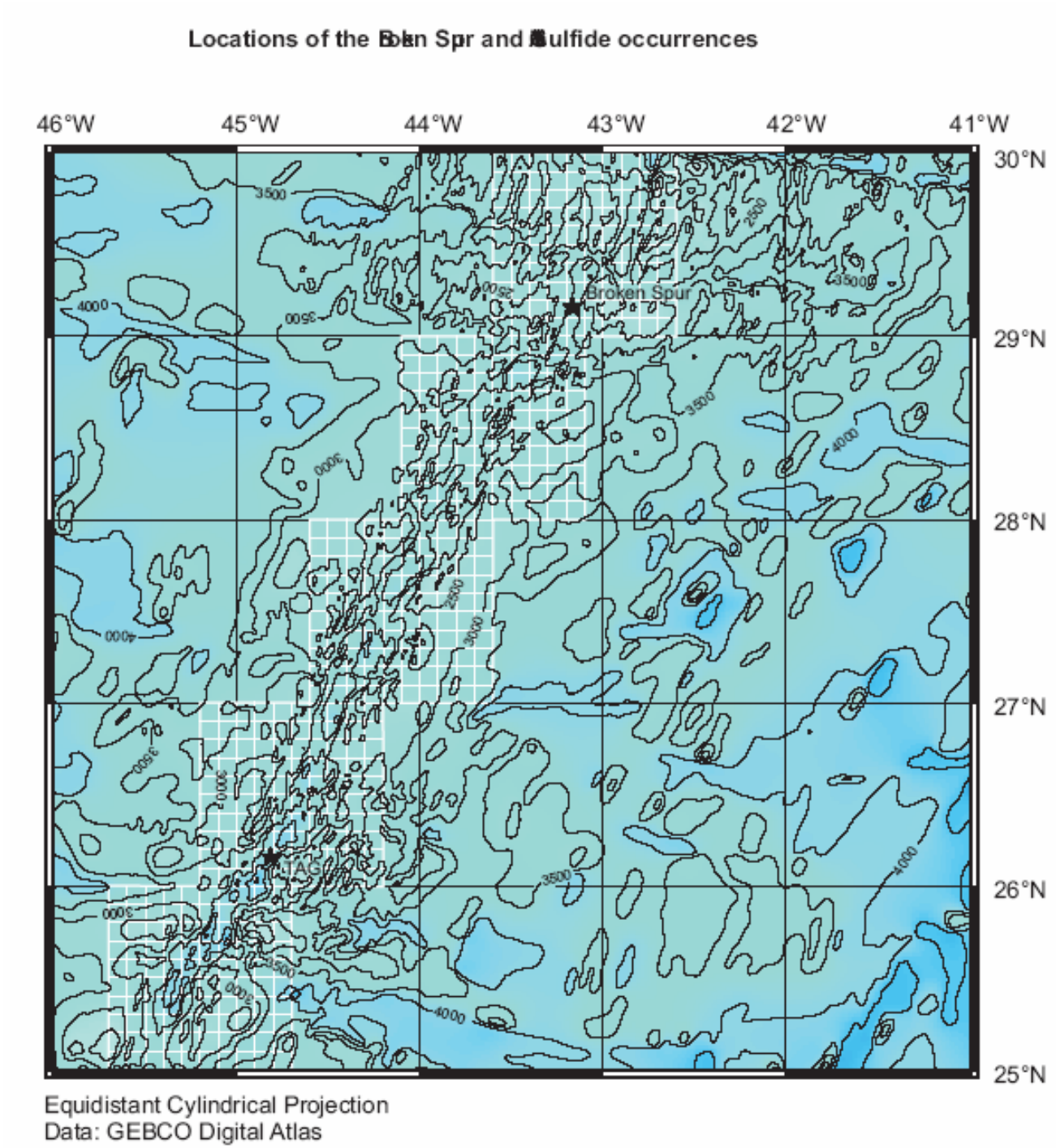


Figure A6. Examples of commercial exploration licenses in P.N.G and New Zealand. The original prospecting licenses of Neptune Minerals in New Zealand (A) were 33,000 km sq. in 1999 (red line) and were reduced to a tenement of 7,790 km sq. (24%) in 2003 (blue line) (www.neptuneminerals.com). The licenses of Nautilus Minerals in P.N.G (B) totalled 15,000 km sq. in 1996, and 2,500 km sq. (17%) have now been identified that contain the two most prospective areas in the Eastern Manus Basin (www.nautilusminerals.com). In these examples, exploration licenses based on 100 contiguous blocks would not have permitted all of the known sulphide occurrences to be included in a single tenement.

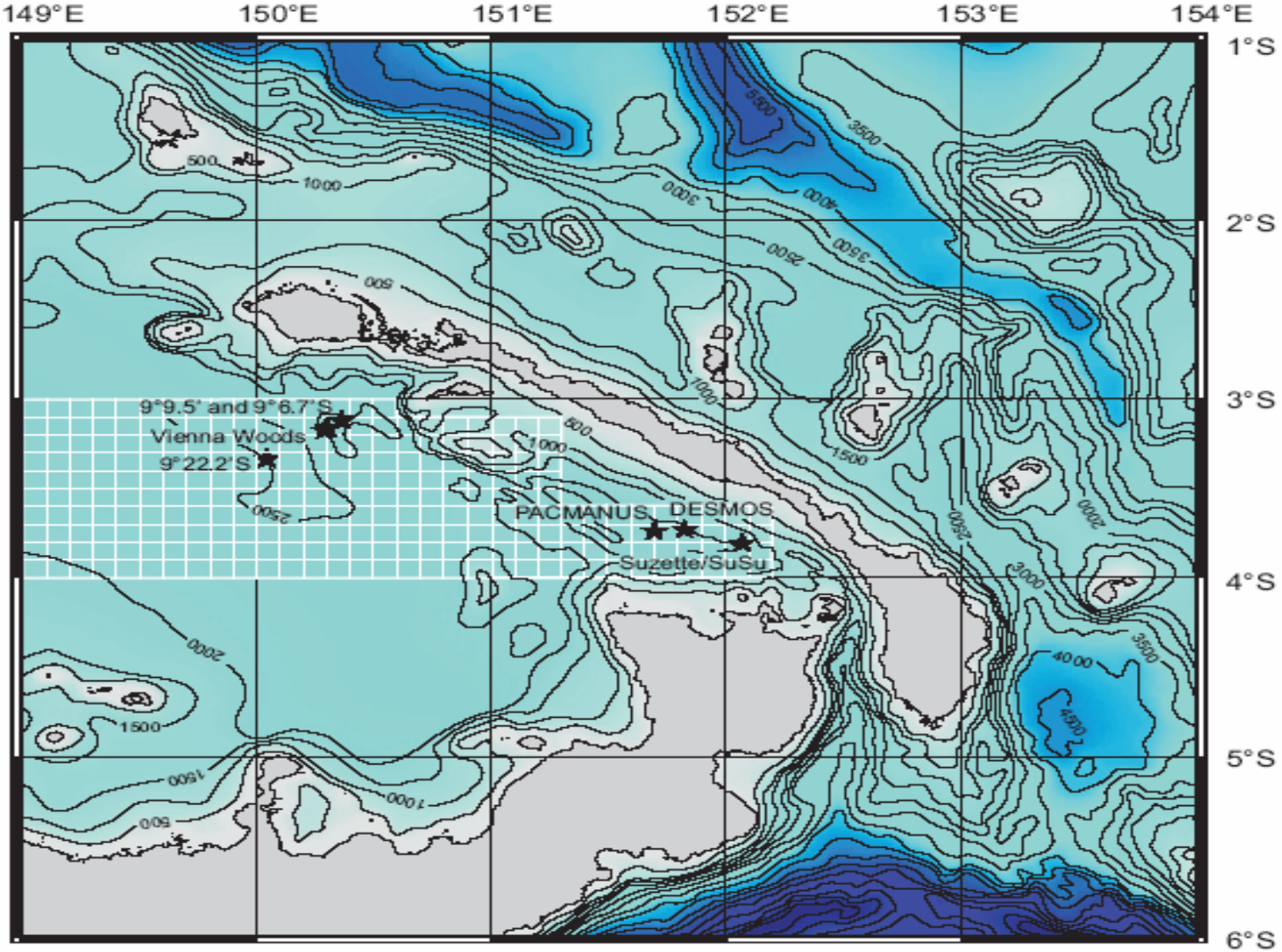
Locations of the sulfide occurrences near 9°50'N, 9°46'N, 9°39°N, and 9°16°N



Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

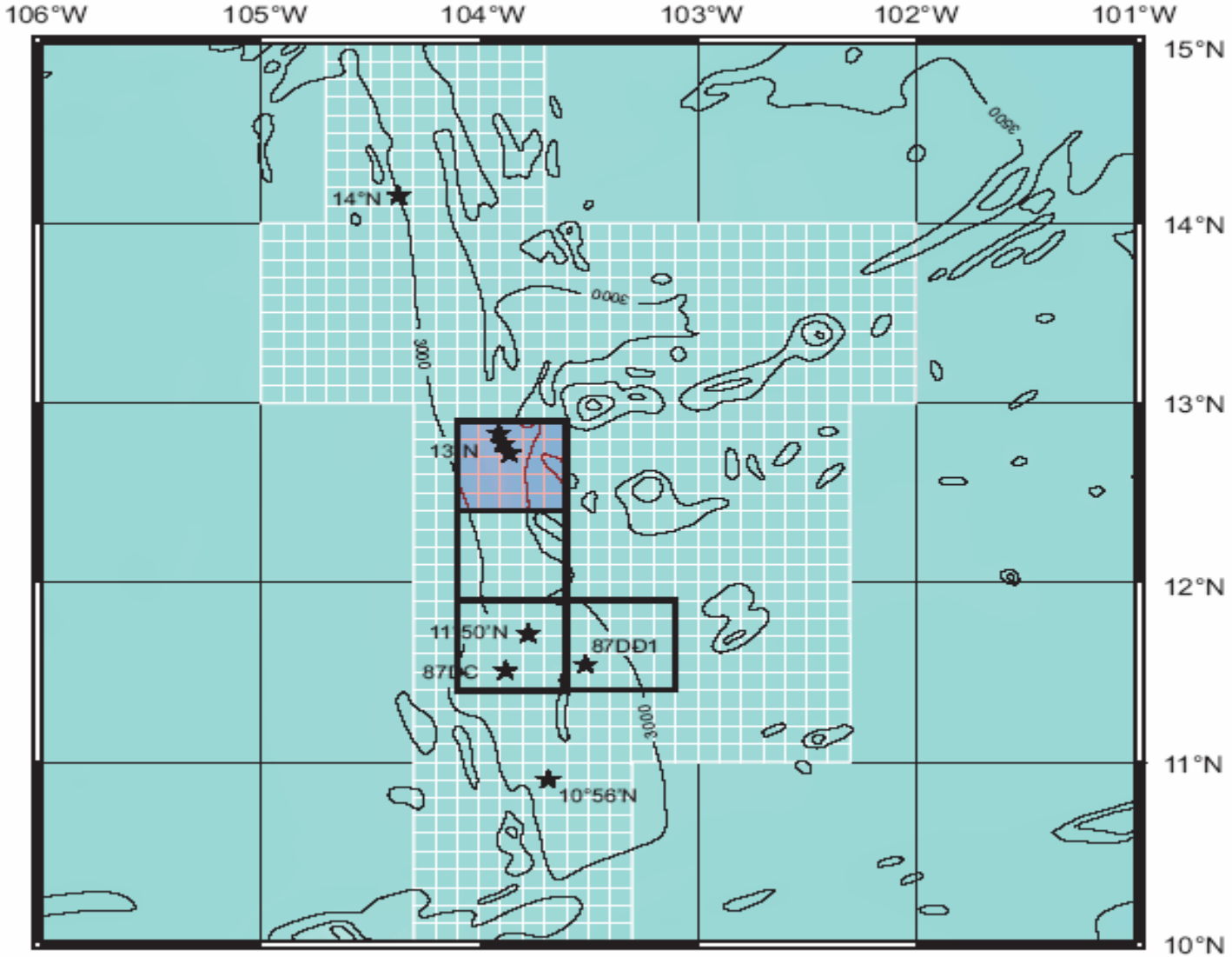

Locations of the Broken Spur and TAG sulfide occurrences
46°W
45°W
44°W
43°W
42°W
41°W
30°N
29°N
28°N
27°N
26°N
25°N
Broken Spur
TAG
3500
4000
3000
2500
Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

Locations of the sulfide occurrences at PACMANUS, DESMOS, Suzette/SuSu, Vienna Woods, and the fields near 9°9.5'S, 9°6.7'S, and 9°22.2'S

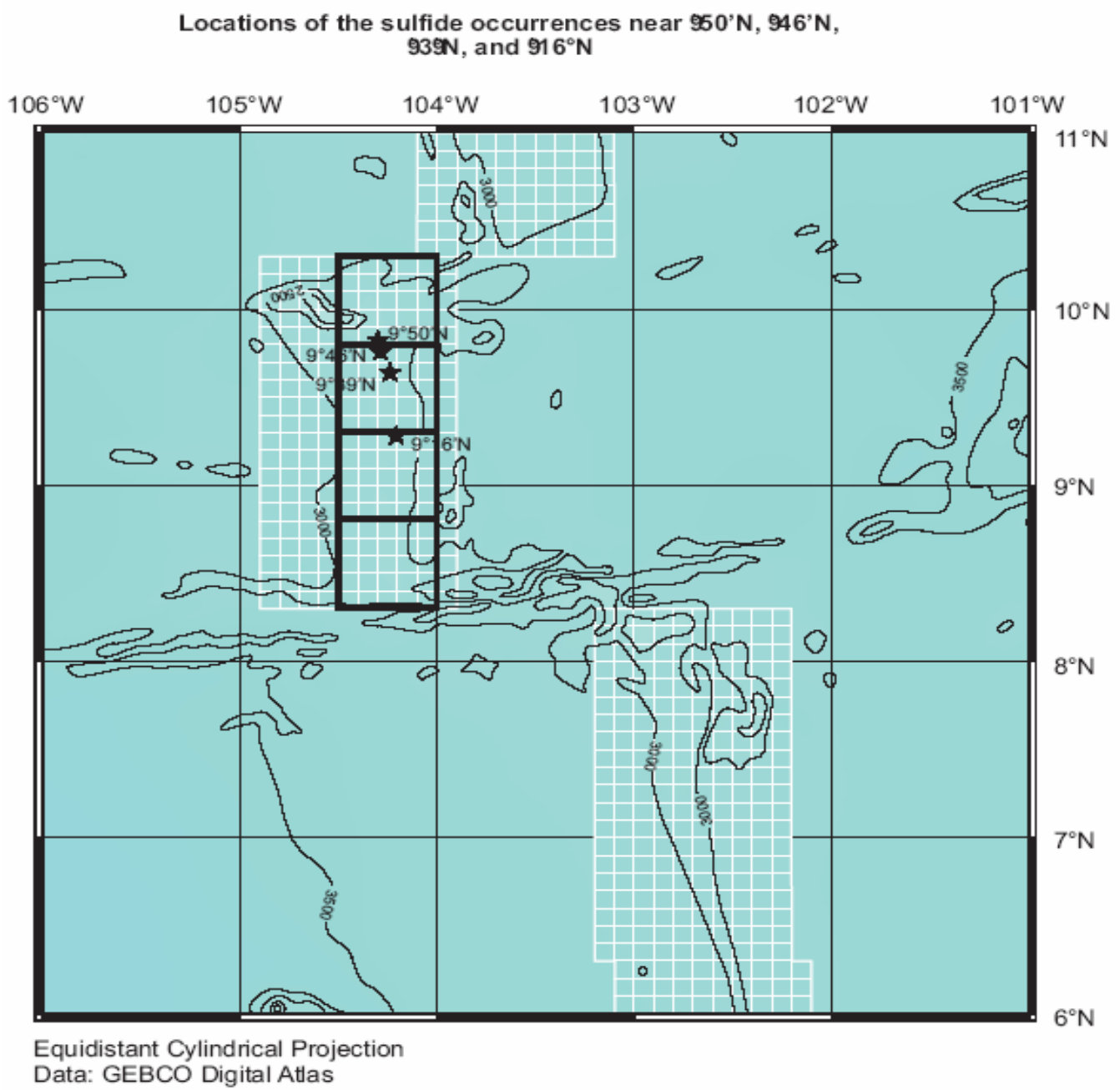


Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

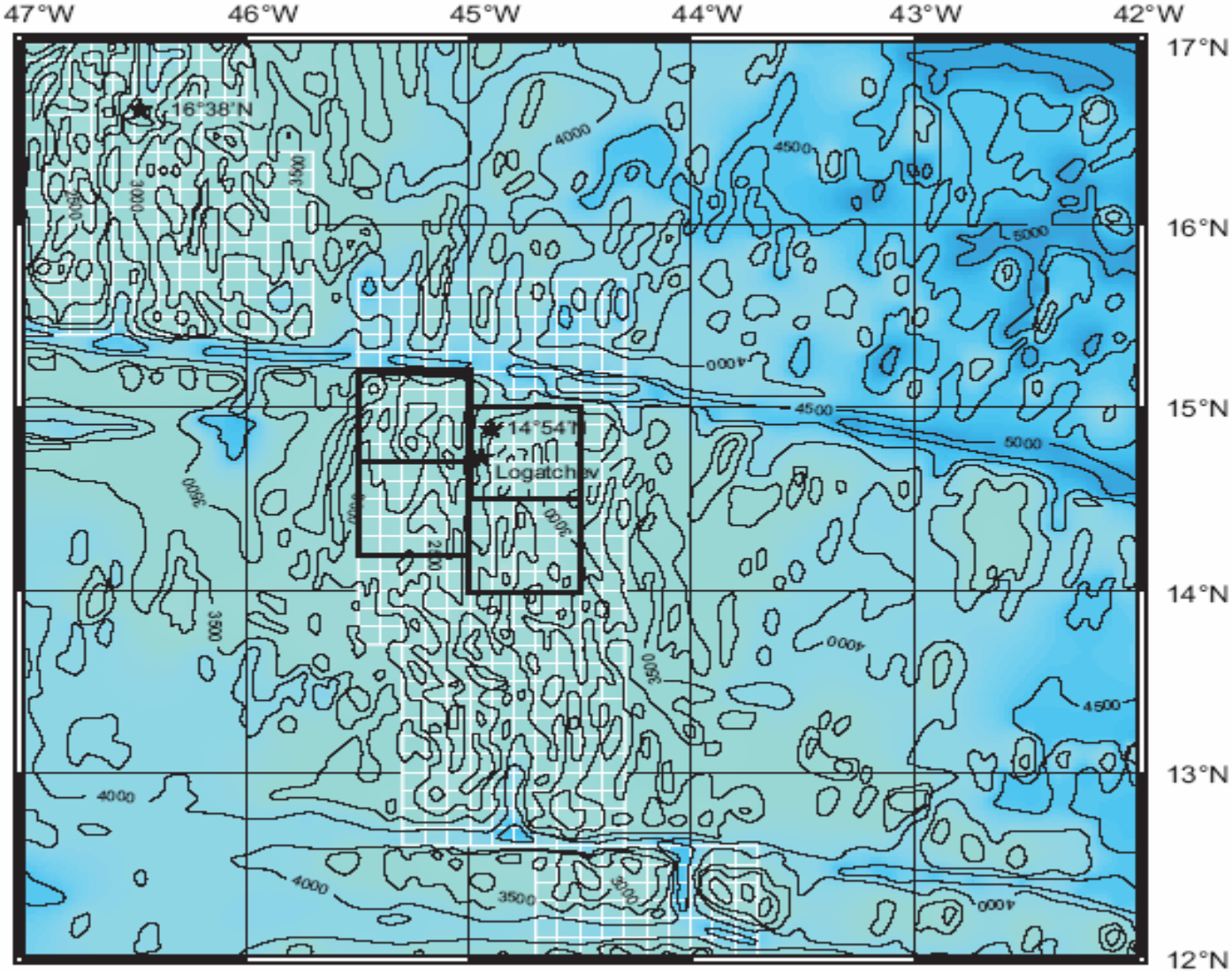
Locations of the sulfide occurrences near 14°N, 13°N, 11°50'N, 10°56'N, and at the 87D-D1 and 87D-C Seamounts



Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

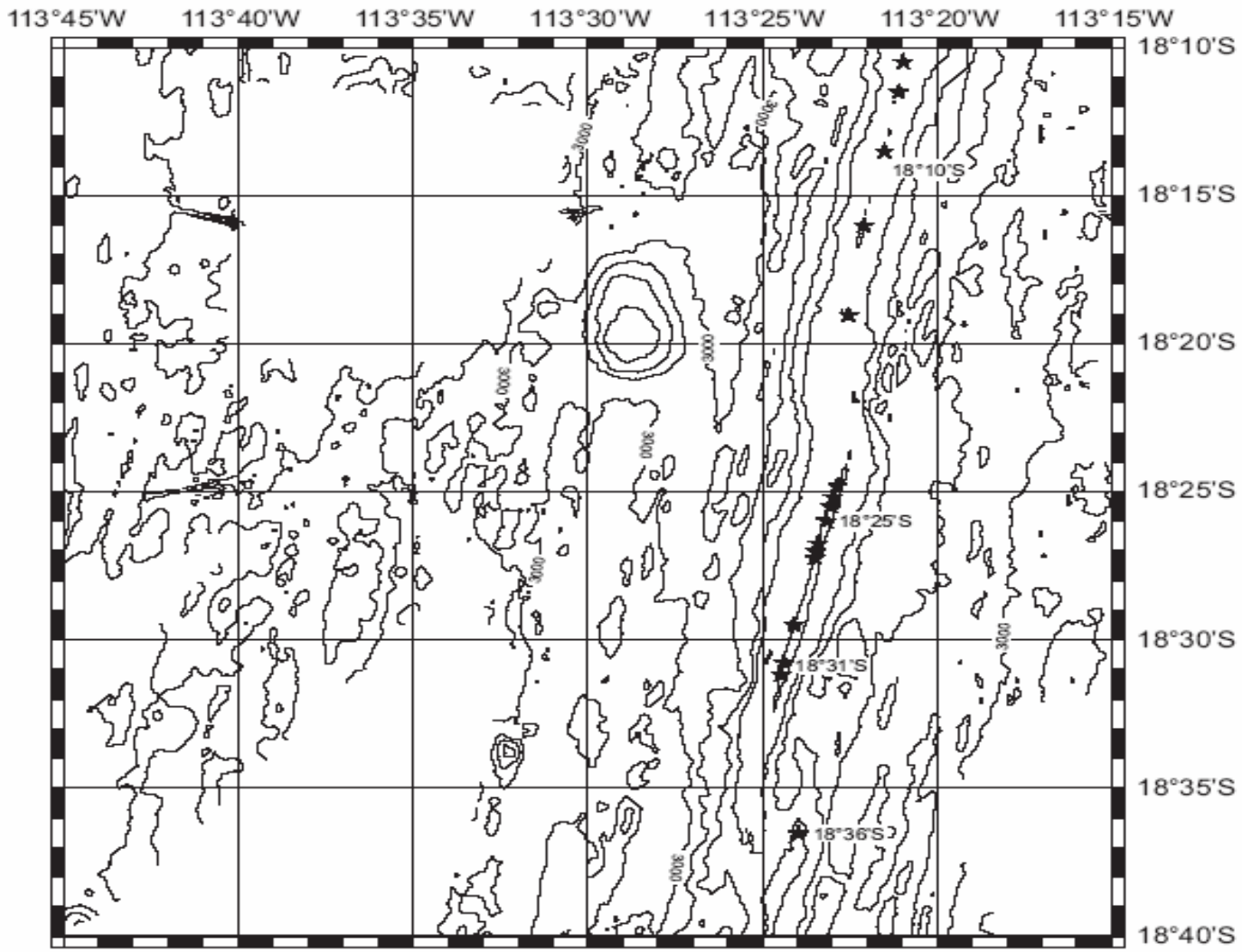

Locations of the sulfide occurrences near 9°50'N, 9°46'N, 9°39'N, and 9°16°N
106°W
105°W
104°W
103°W
102°W
101°W
11°N
10°N
9°N
8°N
7°N
6°N
9°50'N
9°46'N
9°39'N
9°16'N
3000
3500
Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

Location of the sulfide occurrences at 16°38'N, 14°54'N, and the Logatchev Field



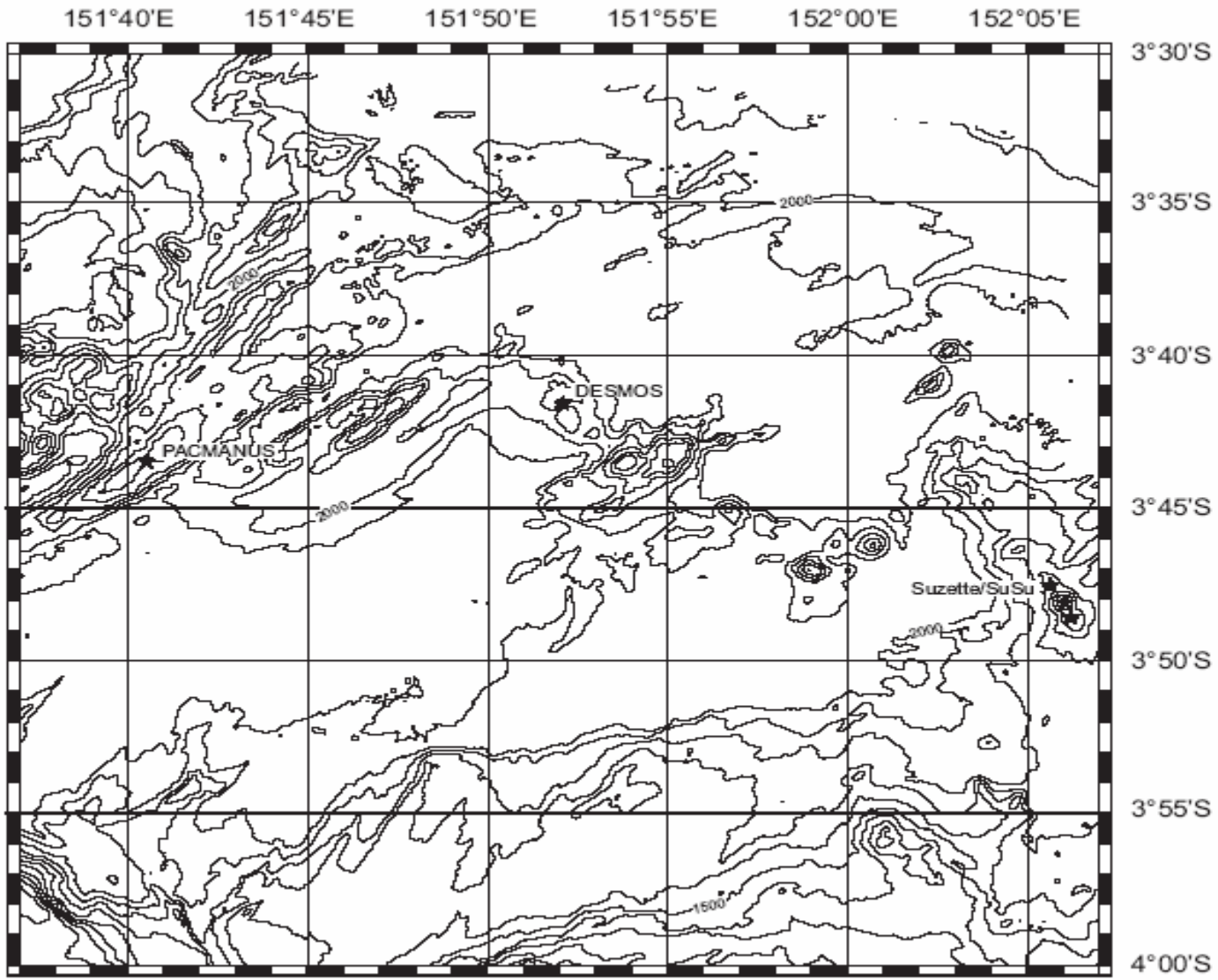
Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

Bathymetry of the sulfide occurrences near 18°S, 19°S, 25°S, and 36°S



Mercator Projection
Data: NOAA Multibeam Bathymetry Database
18°10'S Zone at 18°10.5' to 18°11.5' S, 113°21'W, at 18°13.5'S, 113°21.5'W, at 18°16'S, 113°22'W, and at 18°19'S, 113°22.5'W (Auzende et al., 1994)
18°25'S Zone at 18°24.8' to 18°27.6'S, 113°23.5' to 113°24.0'W (Marchig et al., 1988; Auzende et al., 1994)
18°31'S Zone at 18°29.5' to 18°31.3'S, 113°24.5' to 113°25'W (Renard et al., 1985; Bäcker et al., 1985; Marchig et al., 1988; Auzende et al., 1994)
18°36'S Zone at 18°36.5'S, 113°24.0'W (Jollivet et al., 2004)

Bathymetry of the sulfide occurrences at PACMANUS, DESMOS, and Suzette/SuSu Knolls



Mercator Projection
Data: Multibeam Bathymetry from Auzende et al. (2002)
PACMANUS Field at 3°43.5'S, 151°40.3'E (Binns et al., 2002)
DESMOS at 3°41.5'S, 151°52'E (Gena et al., 2001)
Suzette/SuSu at 3°47' to 3°49'S, 152°05.5' to 152°06.5'E (Binns et al., 2004)