Deep-Ocean Mineral Deposits in the Global Ocean

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United Nations, New York, 16 February 2012

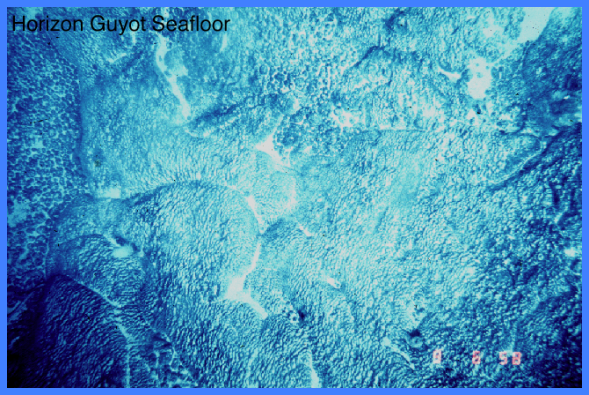
Deep-ocean mineral deposits

Manganese nodules

Form on the vast deep-water abyssal plains

Ferromanganese crusts

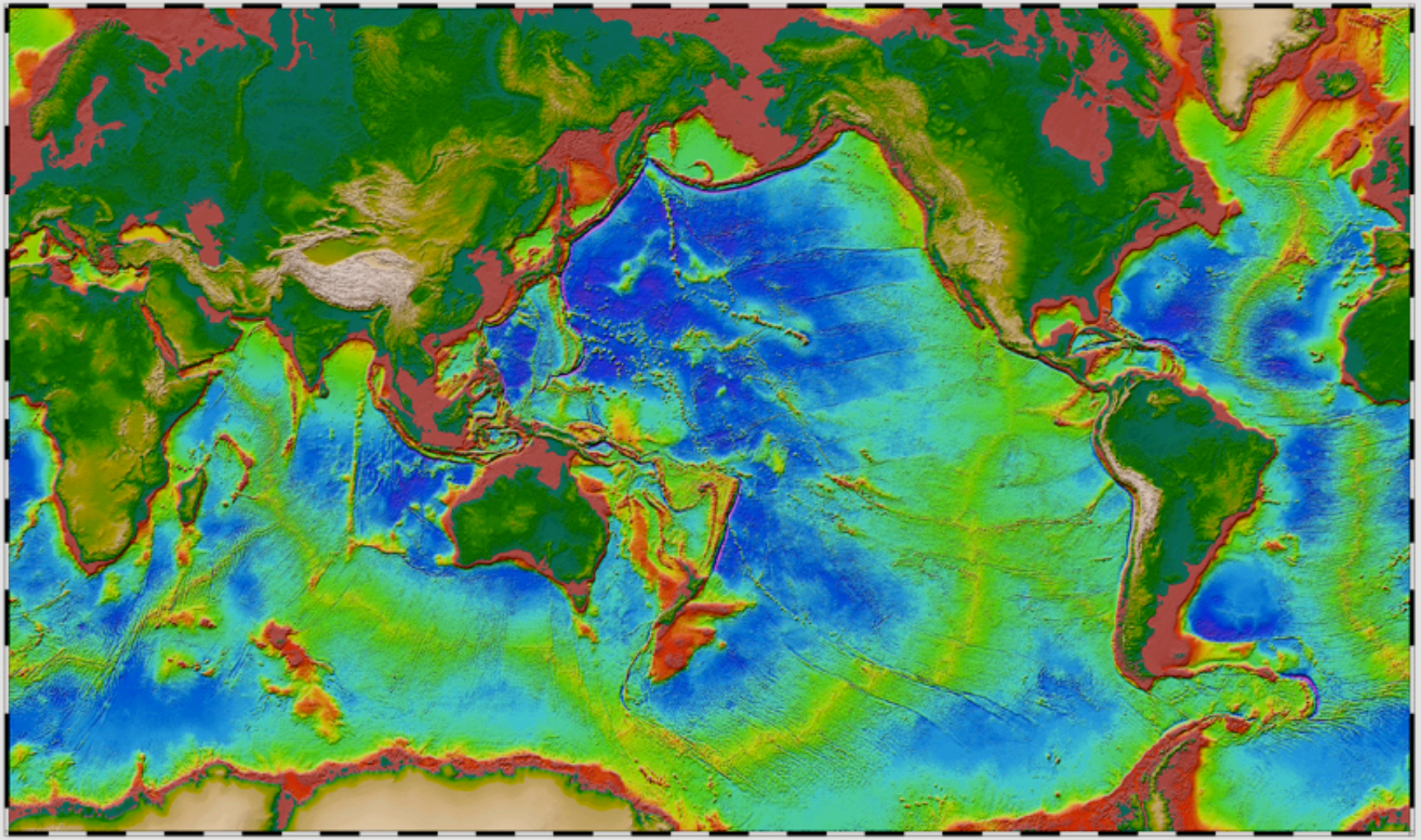
Form on 100,000 seamounts



Seafloor massive sulfides

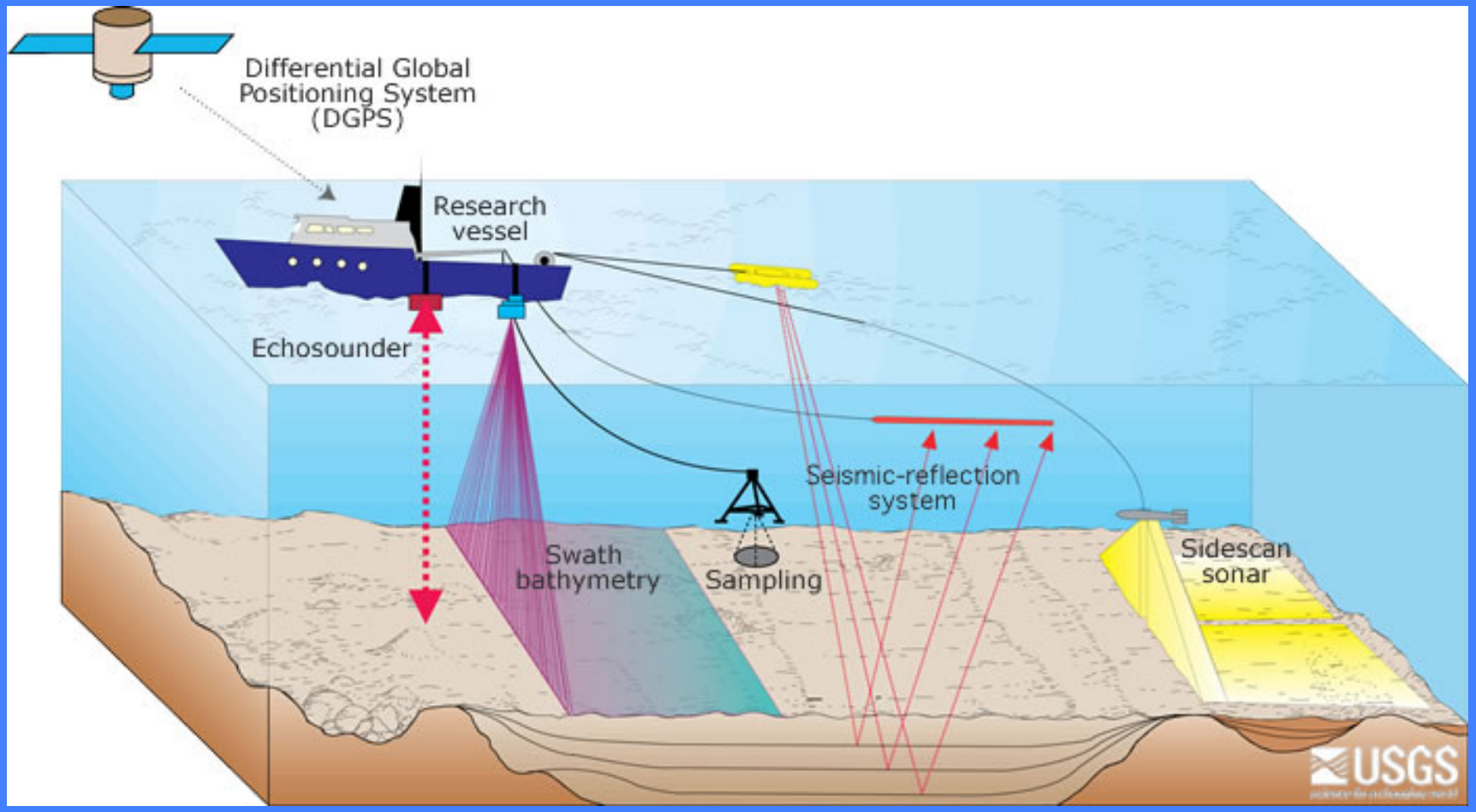
Form at hydrothermal vents along 89,000 km of ridges

Distribution of Marine Mineral Deposits



Research Vessels

Standard Exploration Methods for Deep-Ocean Minerals



Also electromagnetic, ROV, and AUV surveys
Water-column hydrothermal plume tracer surveys

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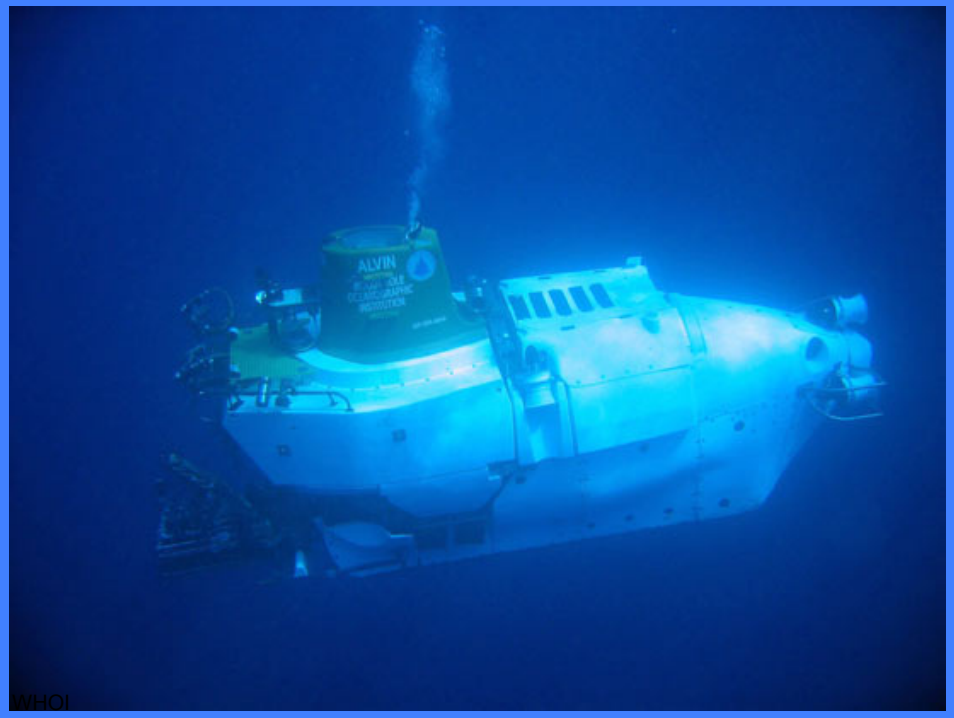
ALVIN



WHOI

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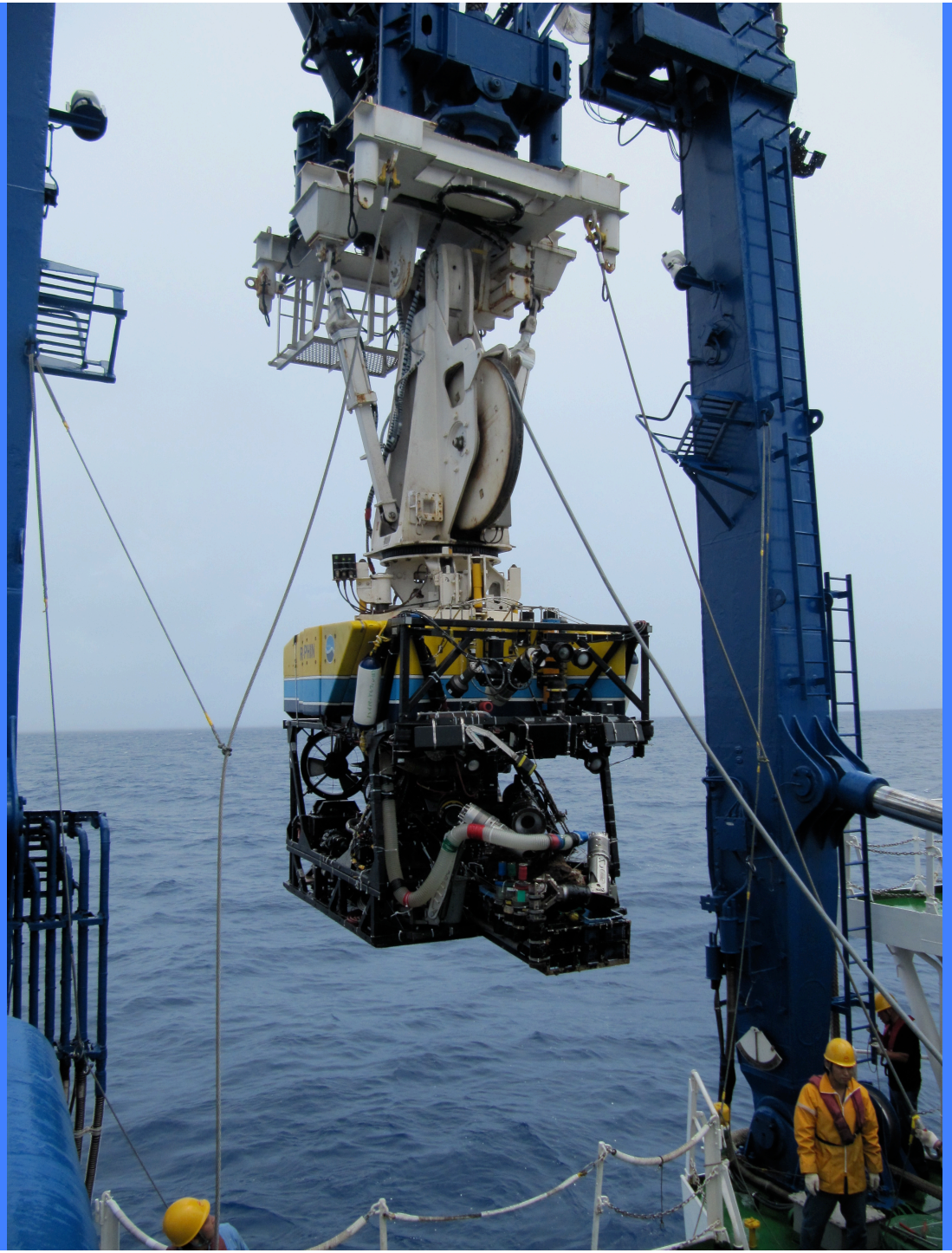
ROV Hyper-Dolphin

On R.V. Natushima

JAMSTEC

Use in combination with Autonomous Underwater Vehicles (AUV)



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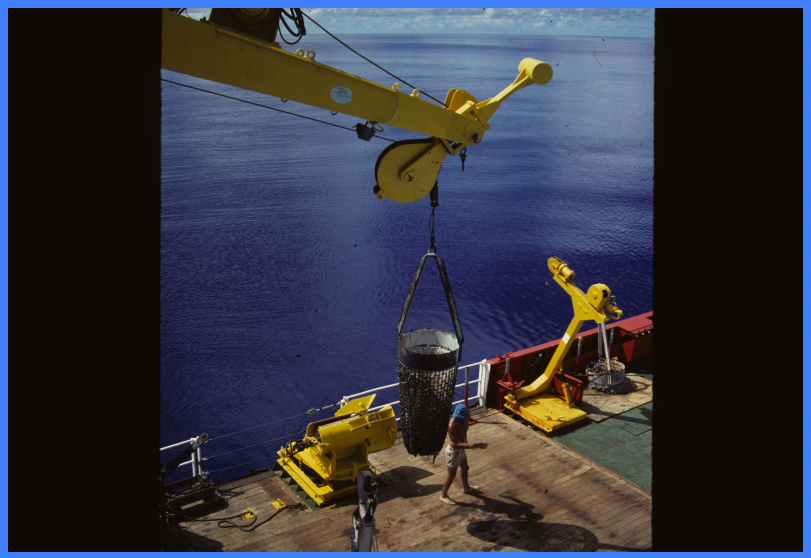
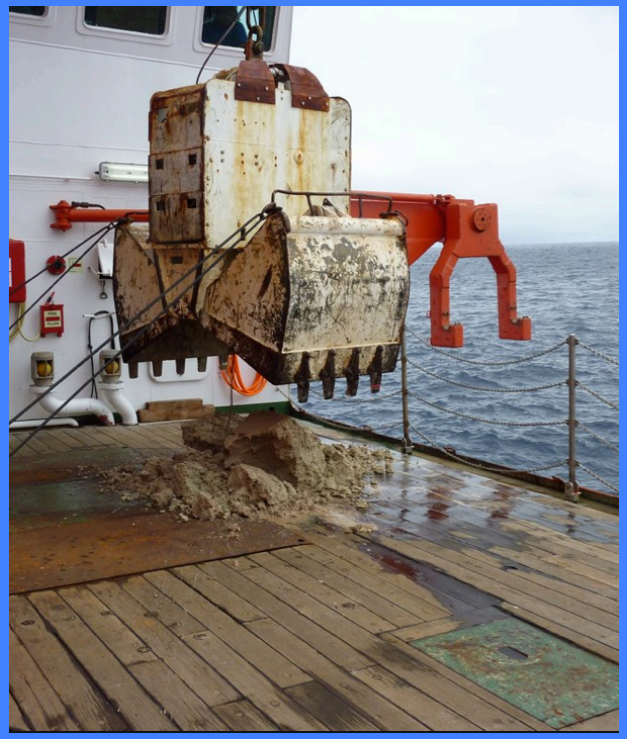
Seafloor Sampling



Circular Chain-Bag Dredge



TV Grab

Spade Corer

Deep-ocean mineral deposits

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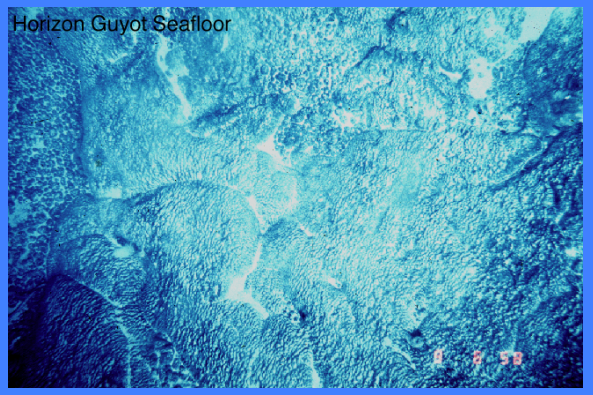
Ferromanganese crusts

Form on 100,000 seamounts



Seafloor massive sulfides

Form at hydrothermal vents along 89,000 km of ridges

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Seafloor Massive Sulfides

Precipitation from hydrothermal & magmatic fluids

Black/white smokers produce sulfide/sulfate chimneys & mounds

Rich in Copper, Zinc, Lead, Barium, Silver, Gold (Cd, Sb, As, Ga, In)

Ephemeral vent fields

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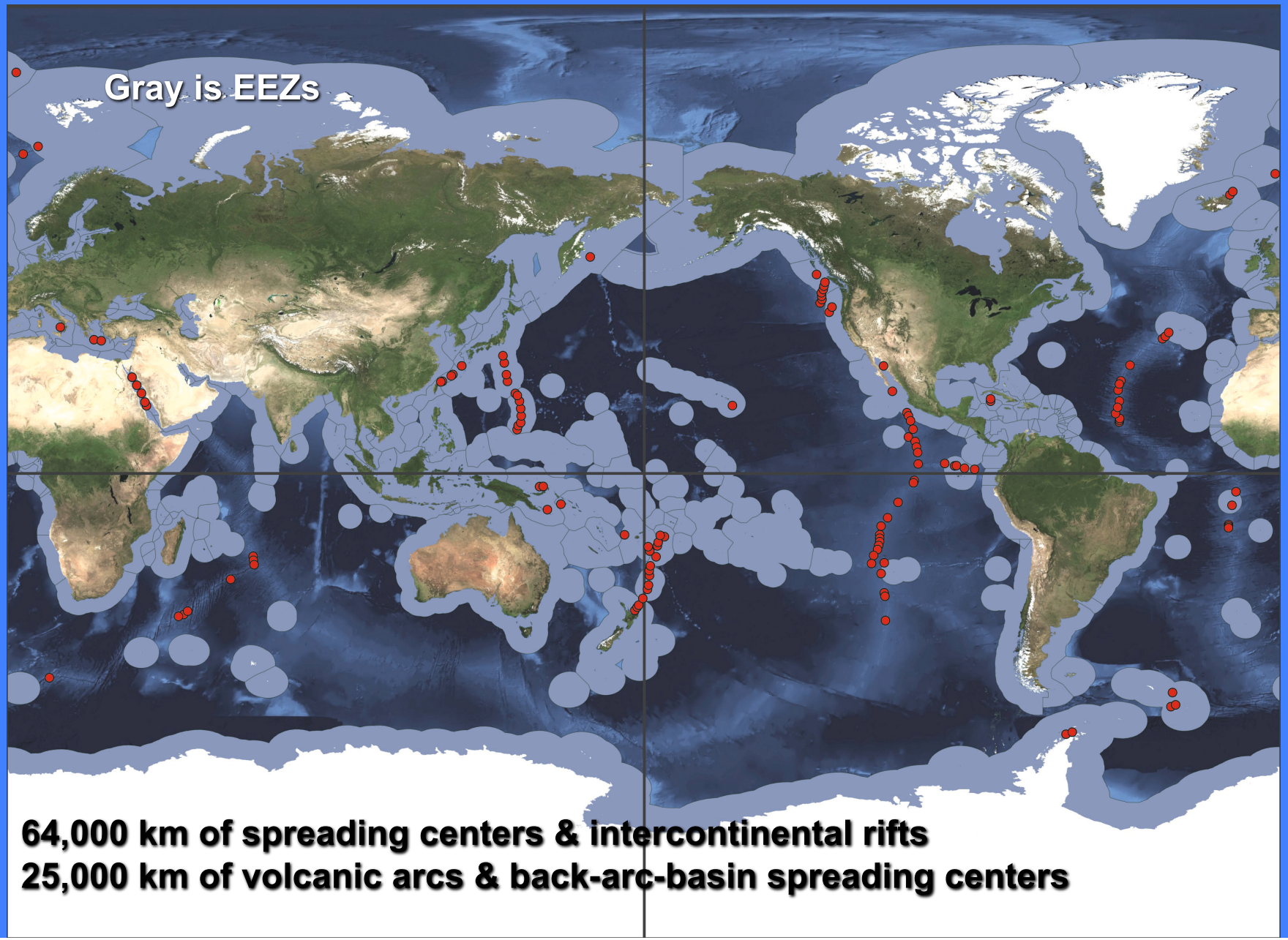
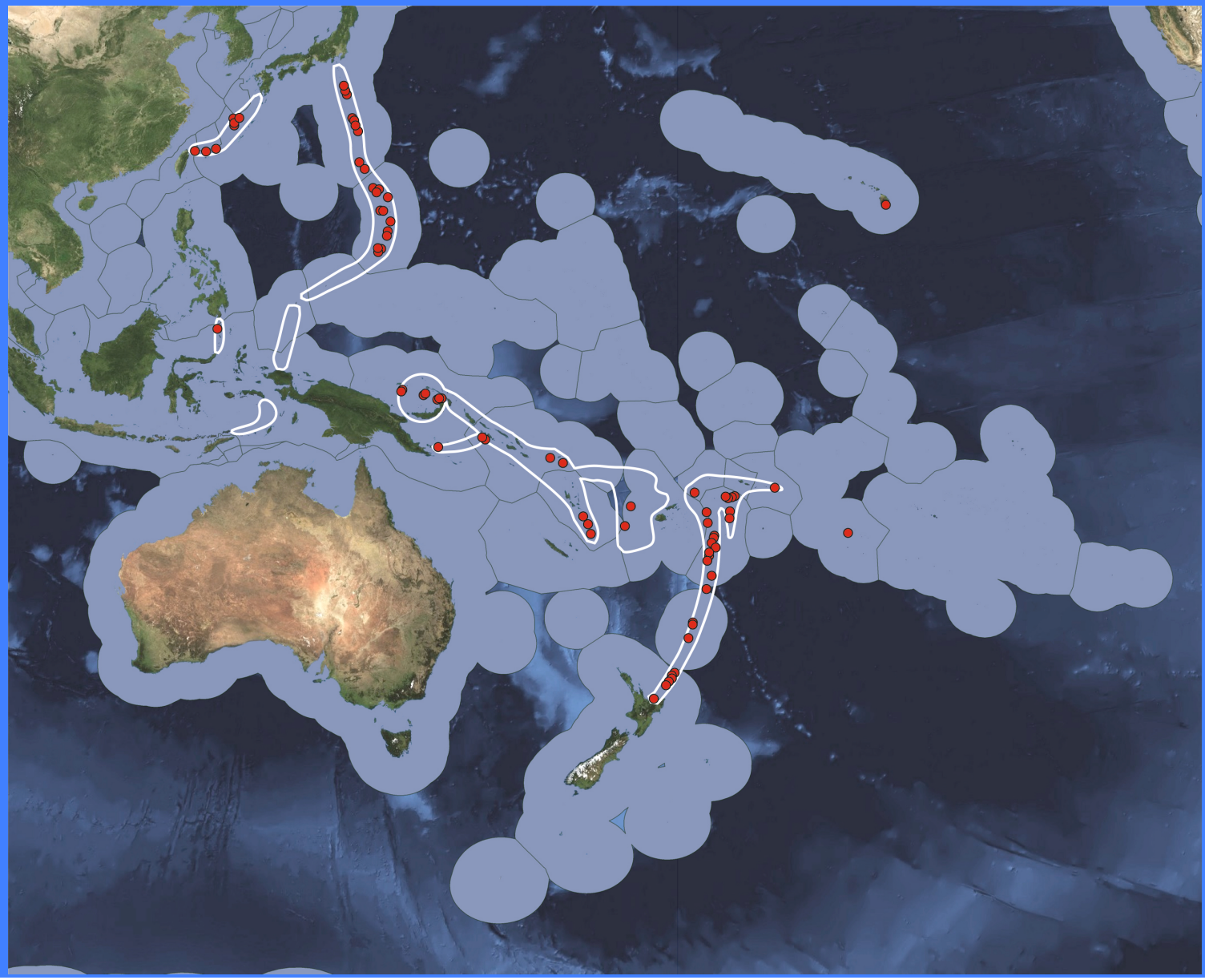
Global Distribution of Hydrothermal Vent Fields



Vent sites in Oceania: Volcanic arc sites occur in EEZs, whereas ridge sites occur mostly in The Area



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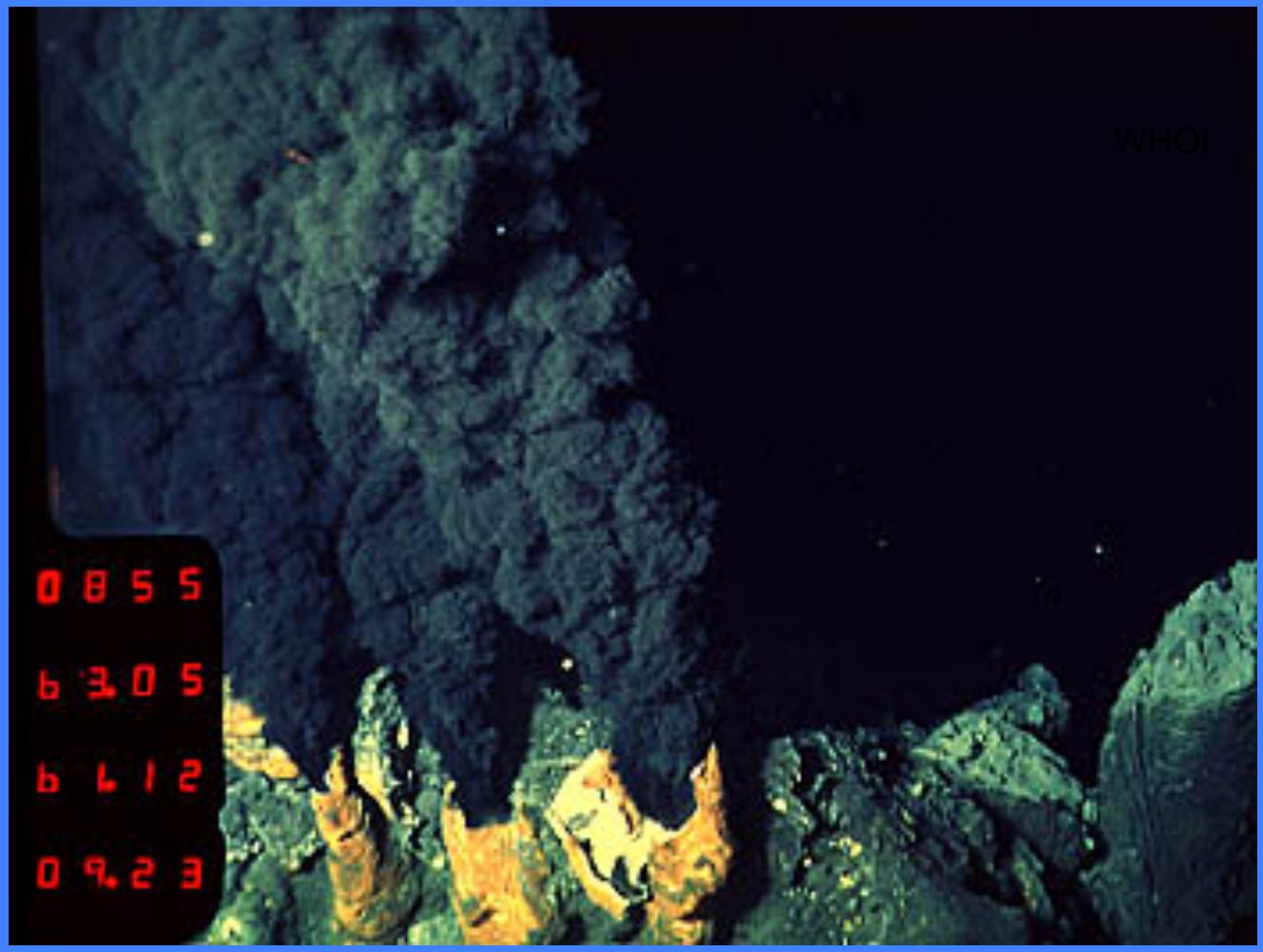
Black Smoker on the East Pacific Rise



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Vent Biology

Ridgeia piscesae; **Juan de Fuca ridge**

Vestimentiferan worms; East Pacific Rise

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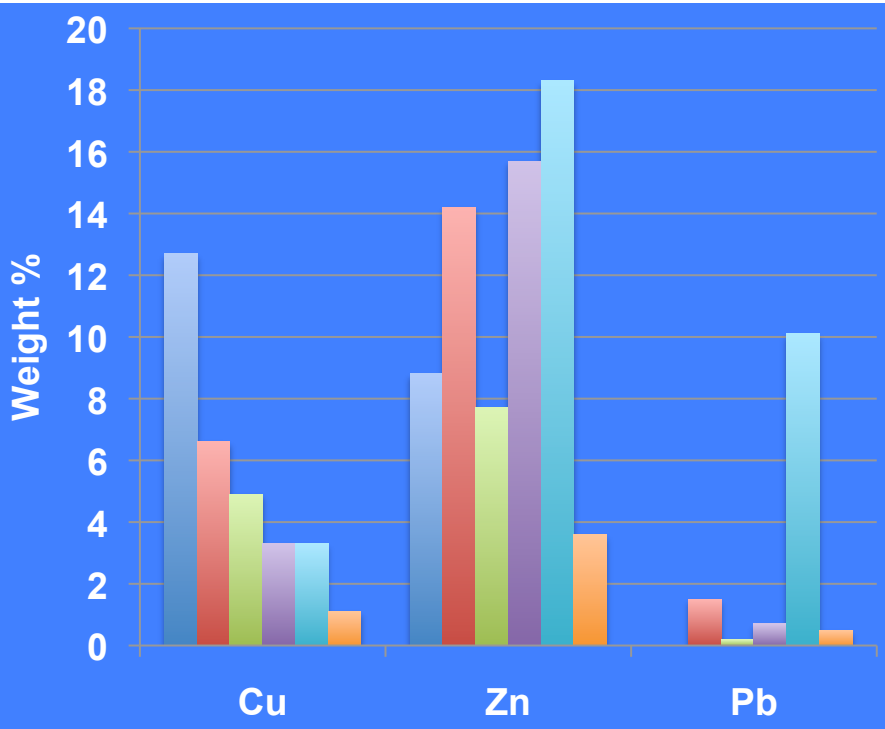
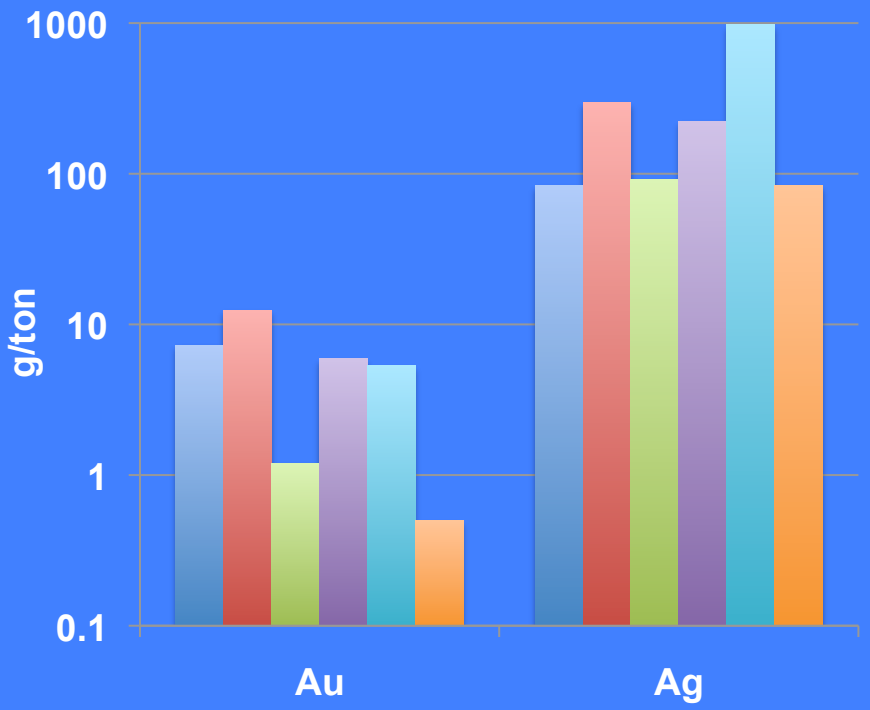
Mussels And Their Associates

Mariana Volcanic Arc
Diffuse-flow system



Composition of different types of seafloor massive sulfide deposits



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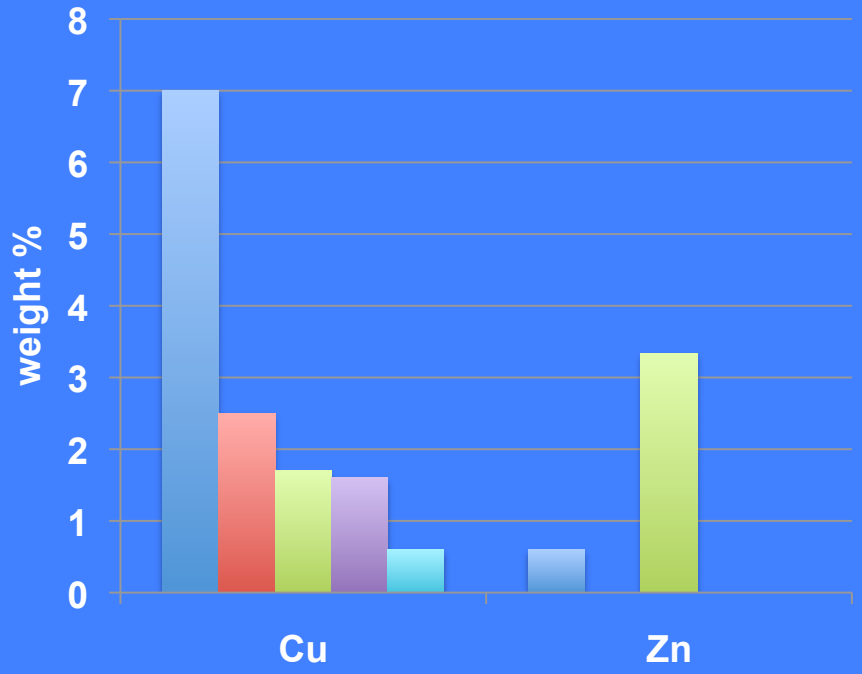
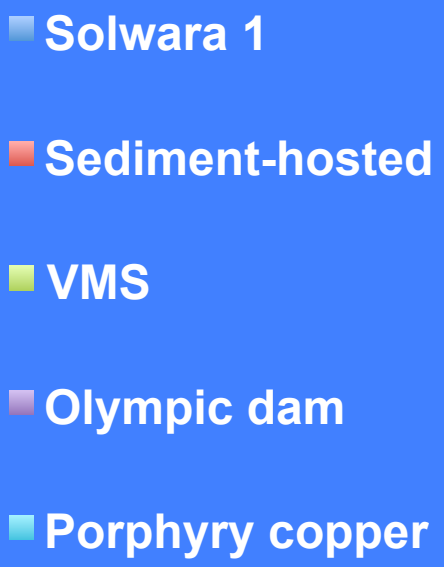
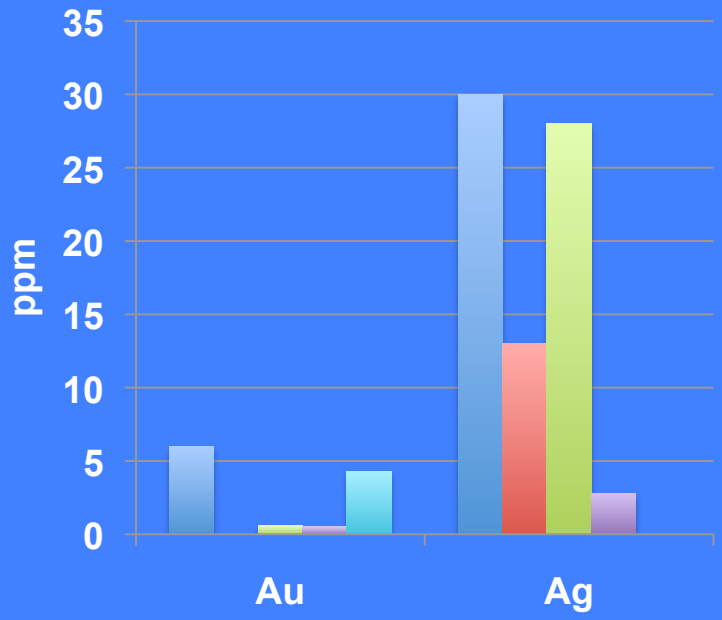




Mean composition of Nautilus Solwara 1 marine mine compared to all major types of land-based copper deposits



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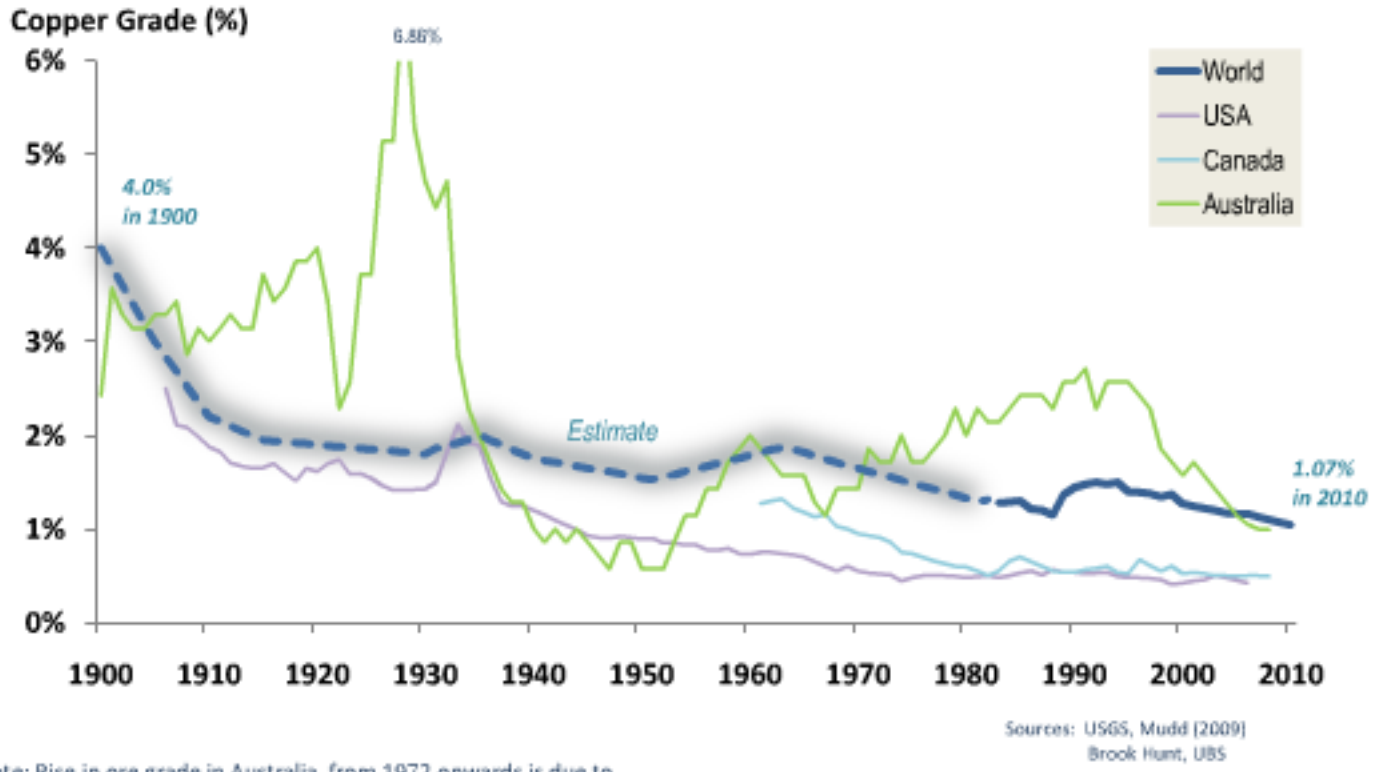
Ore grades mined have declined over time

Copper ore grade for World and selected countries: 1900-2008



Sources: USGS, Mudd (2009)
Brook Hunt, UBS

Note: Rise in ore grade in Australia from 1972 onwards is due to startup of the high-grade Olympic Dam mine

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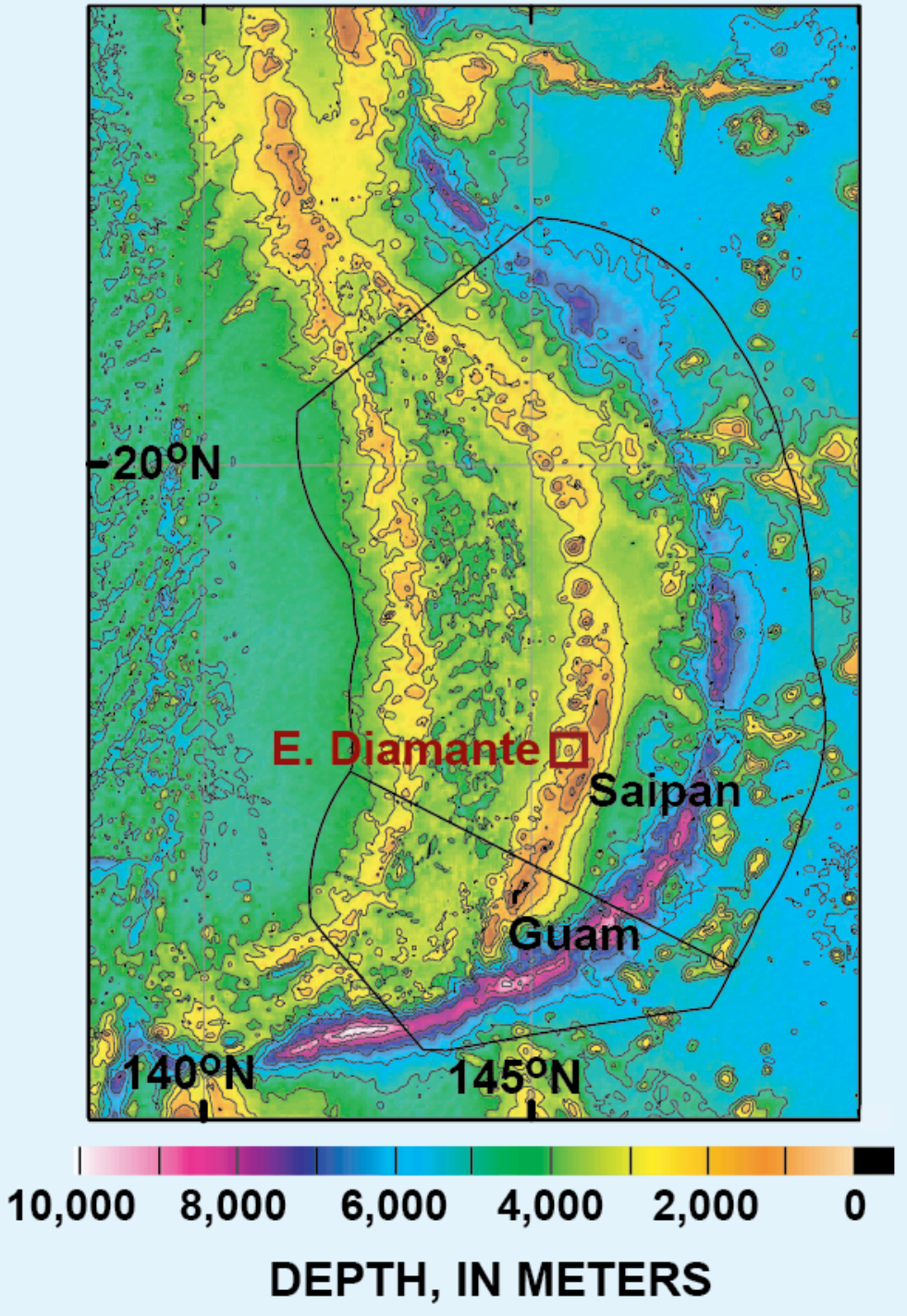
Mariana Volcanic Arc

New discoveries of seafloor Massive sulfides



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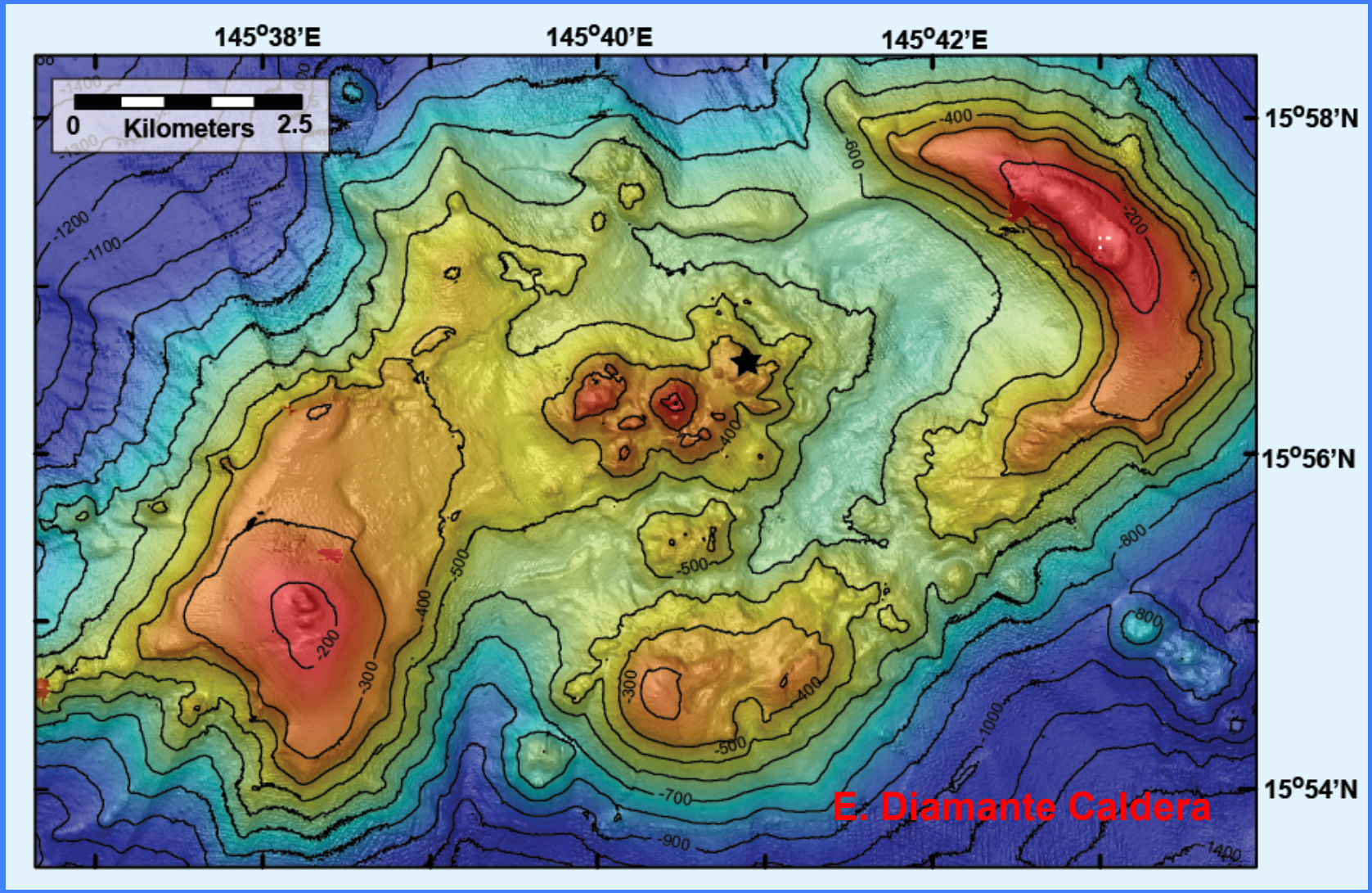
~10 x 4 km caldera
Maximum depth in caldera is ~700 m



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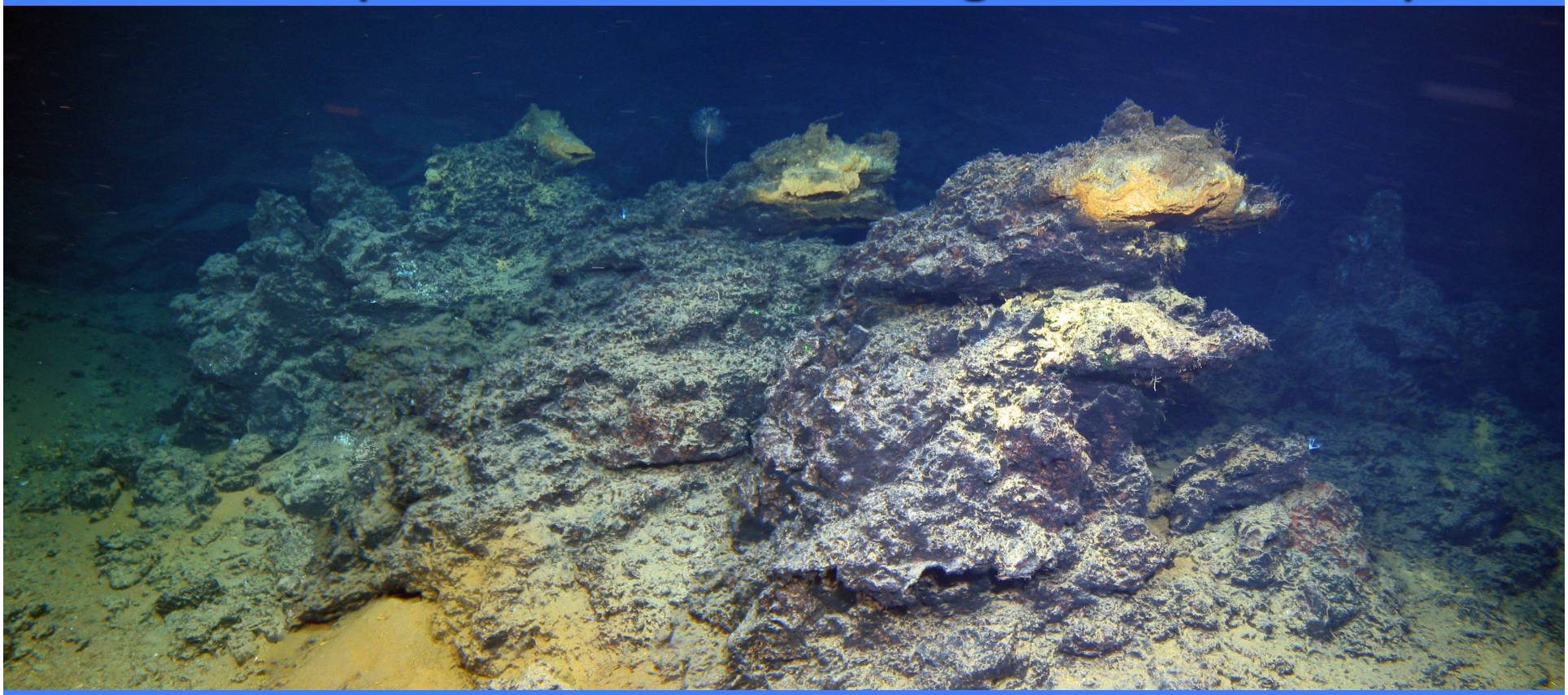
East Diamante caldera hydrothermal mounds (rich in zinc, barium, gold, and silver)



Contain significant rare metals: e.g. cadmium antimony, gallium, indium

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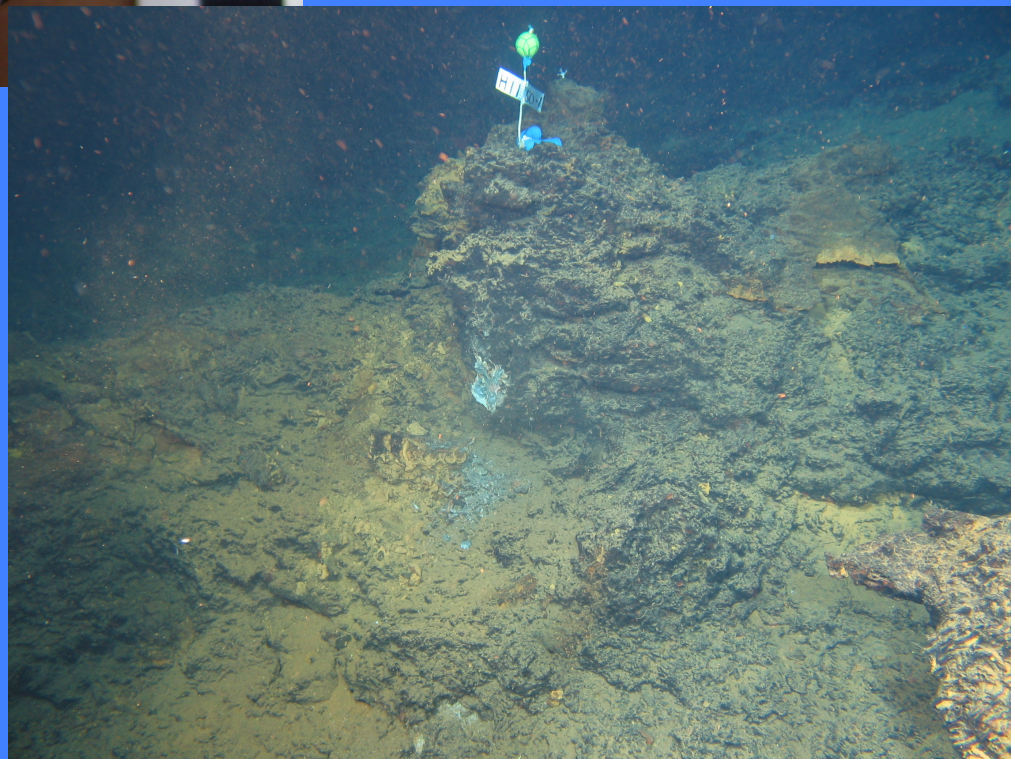
Typical sample

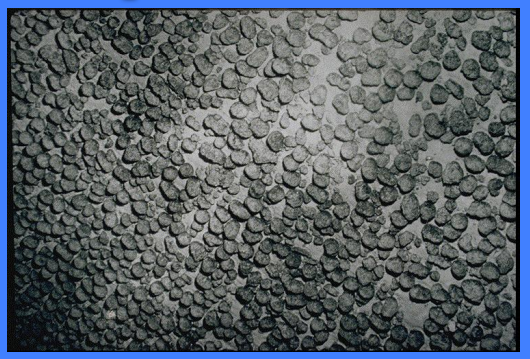
Barium = 22%
Zinc = 19%
Lead = 6%
Copper = 1%
Silver = 386 g/t
Gold = 6.4 g/t



Deep-ocean mineral deposits

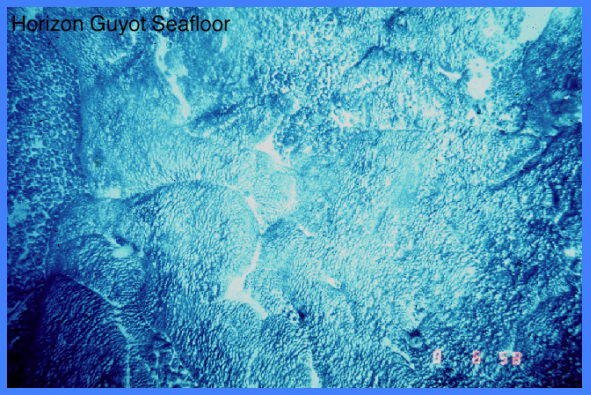
Manganese nodules

Form on the vast deep-water abyssal plains



Ferromanganese crusts

Form on 100,000 seamounts



Seafloor massive sulfides

Form at hydrothermal vents along 89,000 km of ridges

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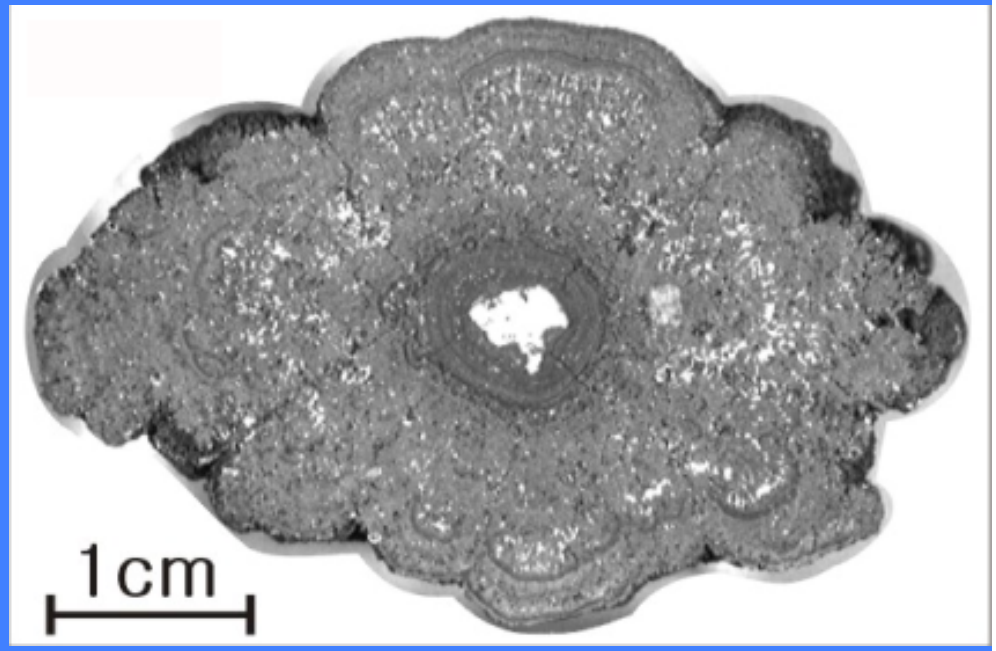
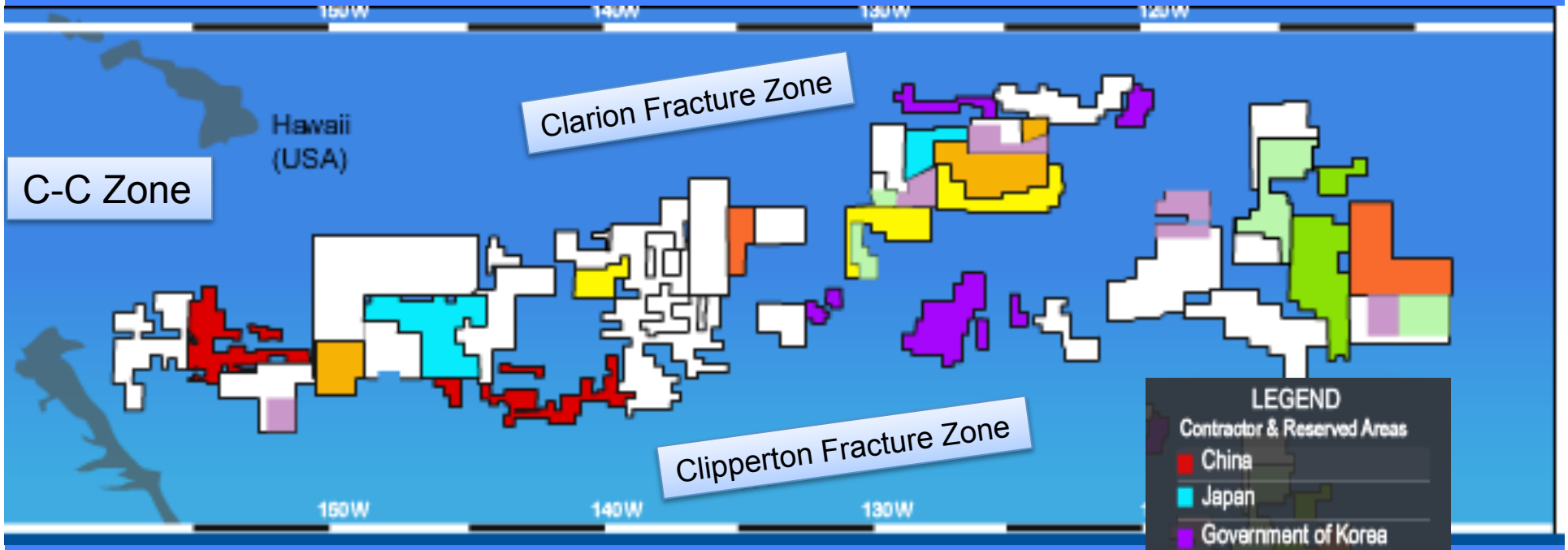
Manganese Nodules

- Form on sediment-covered abyssal plains (4,500-6,500 meters water depths)
- Composed of manganese & iron oxides, with significant amounts of nickel & copper
- Form by precipitation from cold ambient bottom water & from sediment pore fluids

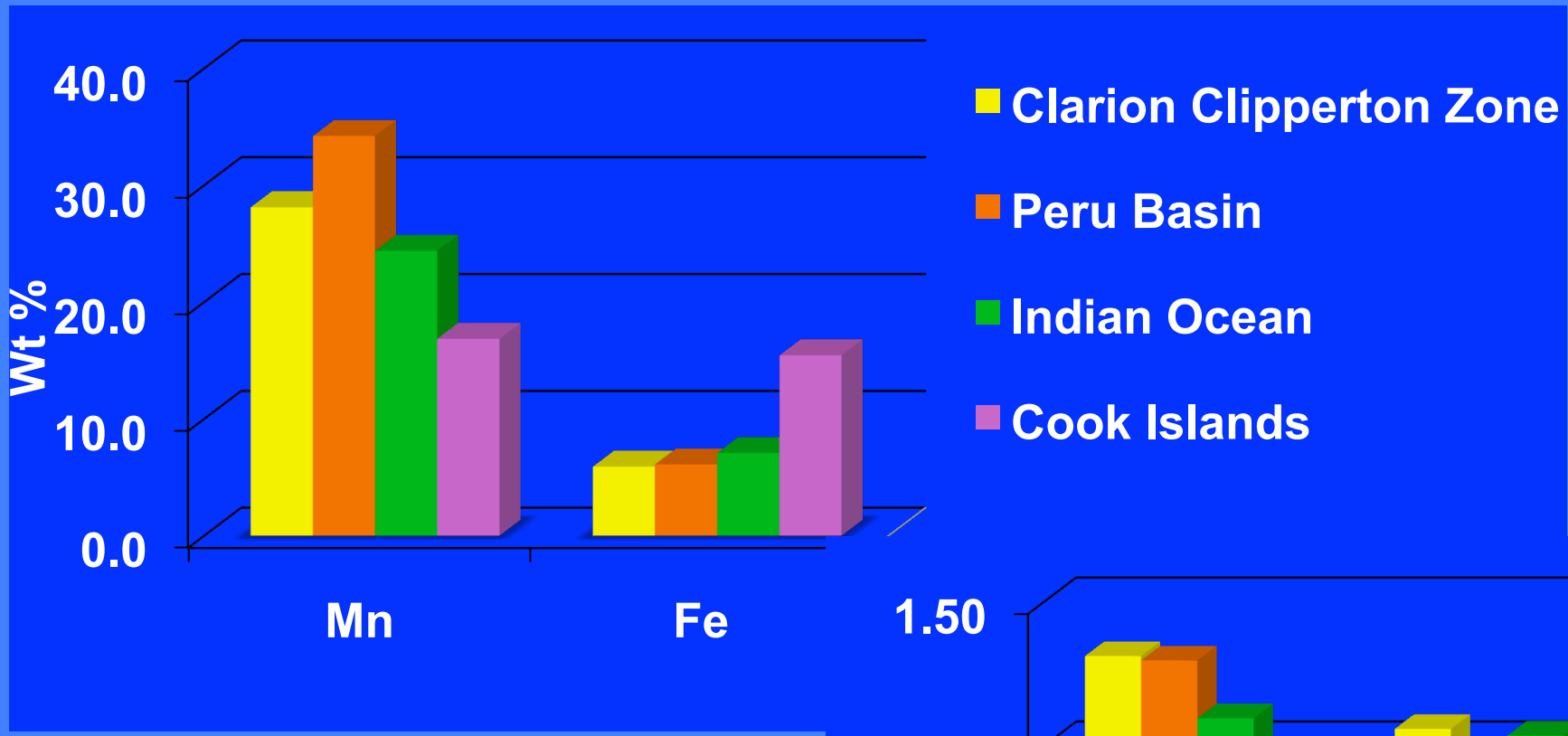


Nine exploration licenses in the CCZ in the East Pacific

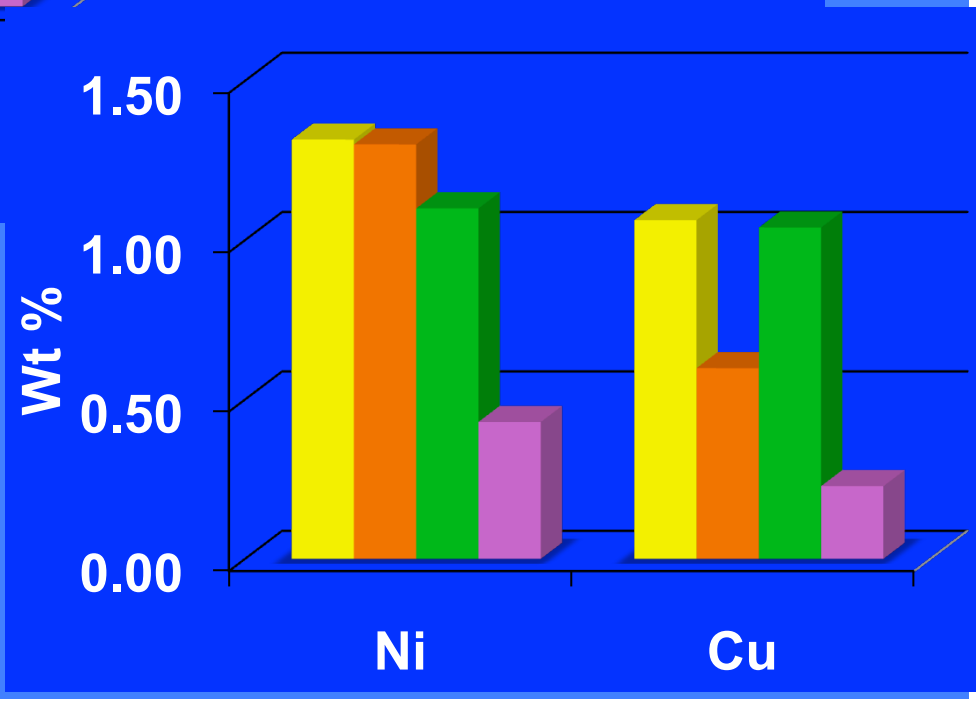


India has a nodule license in Indian Ocean

Global Nodules



Greatest economic interest for Nickel, Copper, and Manganese



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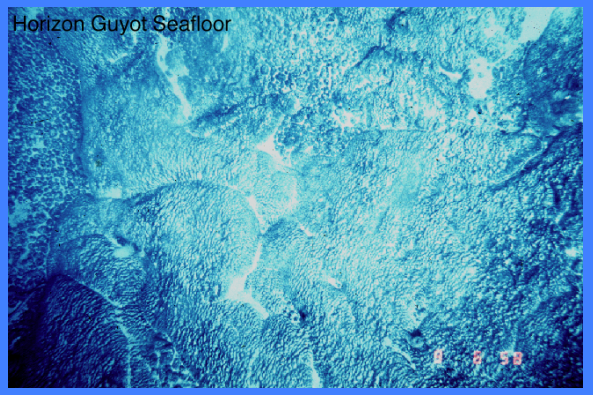


Seafloor massive sulfides

Form at hydrothermal vents along 89,000 km of ridges

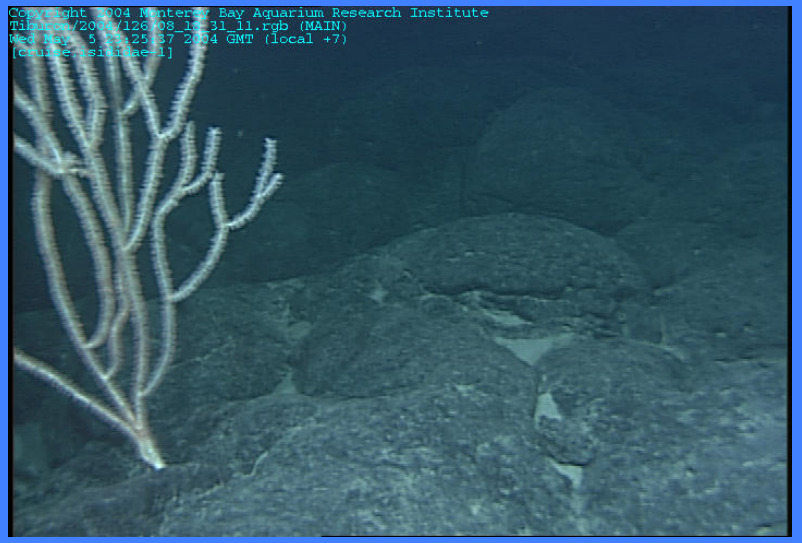
Ferromanganese Crusts

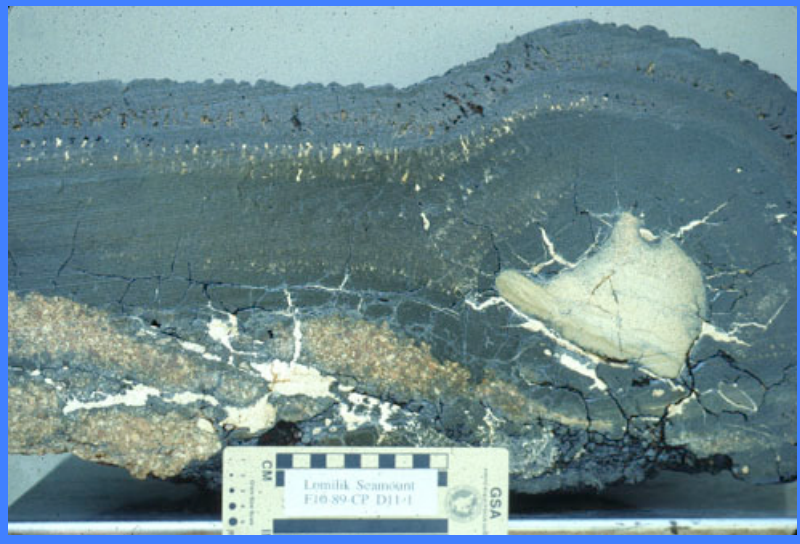
Grow on hard-rock surfaces on seamounts, ridges, and plateaus

Found at water depths of 400-7,000 meters

Thicknesses range from less than 1 to 260 millimeters

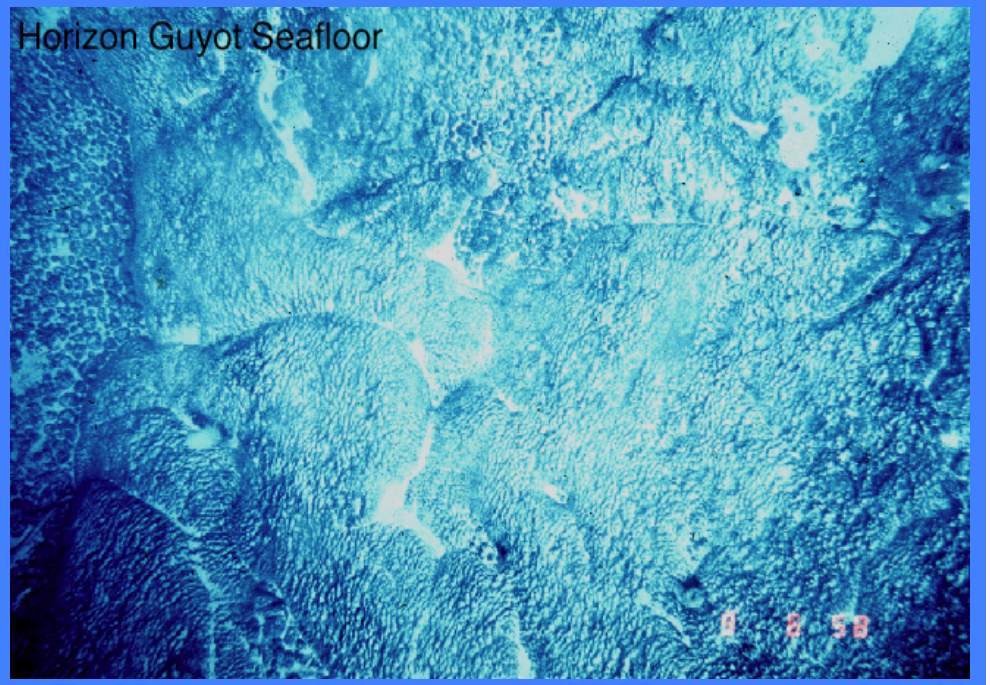
Precipitate from cold ambient bottom water





Distribution of Ferromanganese Crusts

- Arctic to Antarctic on seamounts, ridges, and plateaus
- Thickest crusts occur between water depths of 1500-2500 m
- Most cobalt-rich at ~800-2200 m water depths



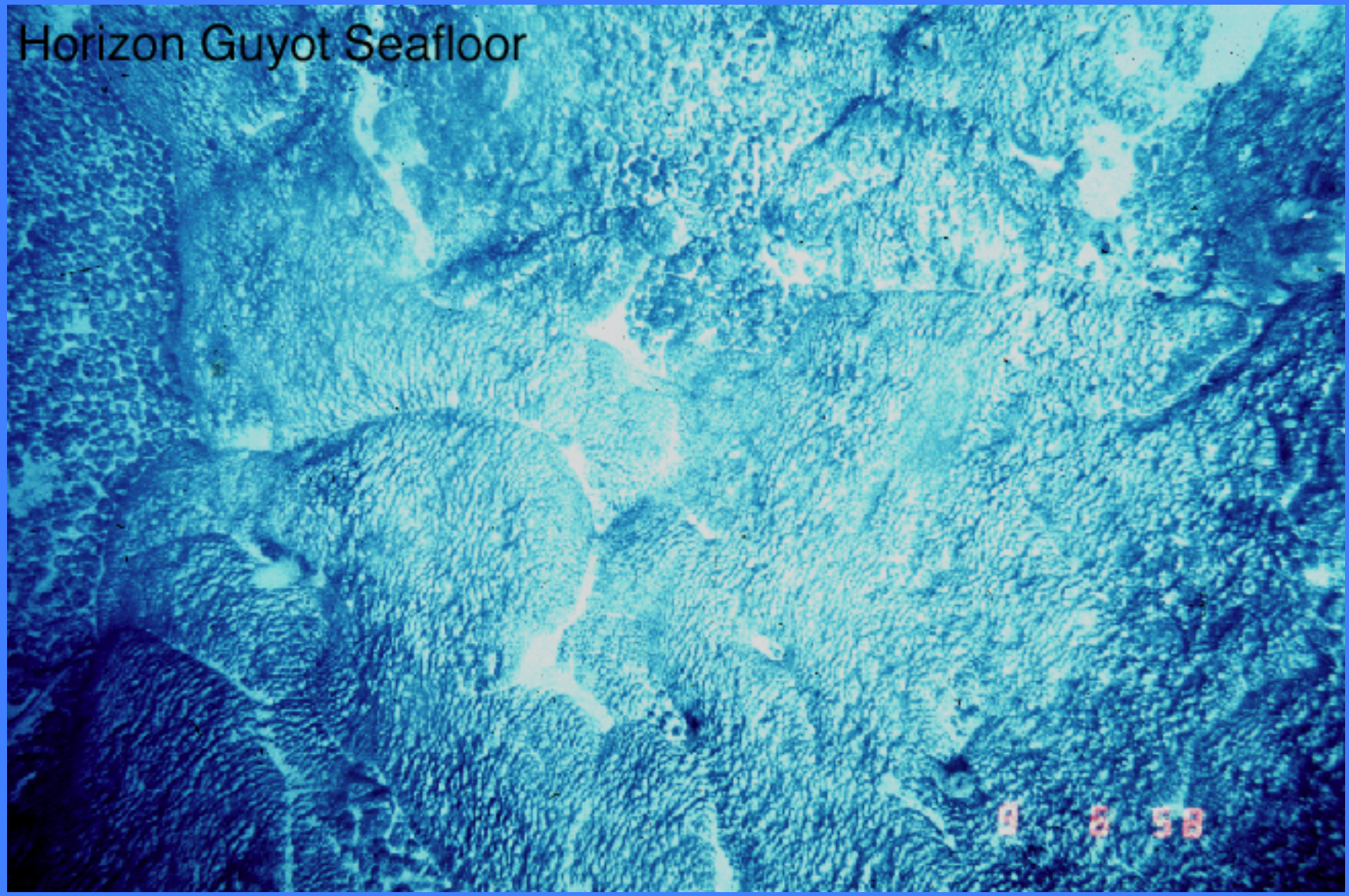
Fe-Mn crust pavement at 2000 m water depth

Important Properties of Fe-Mn crusts

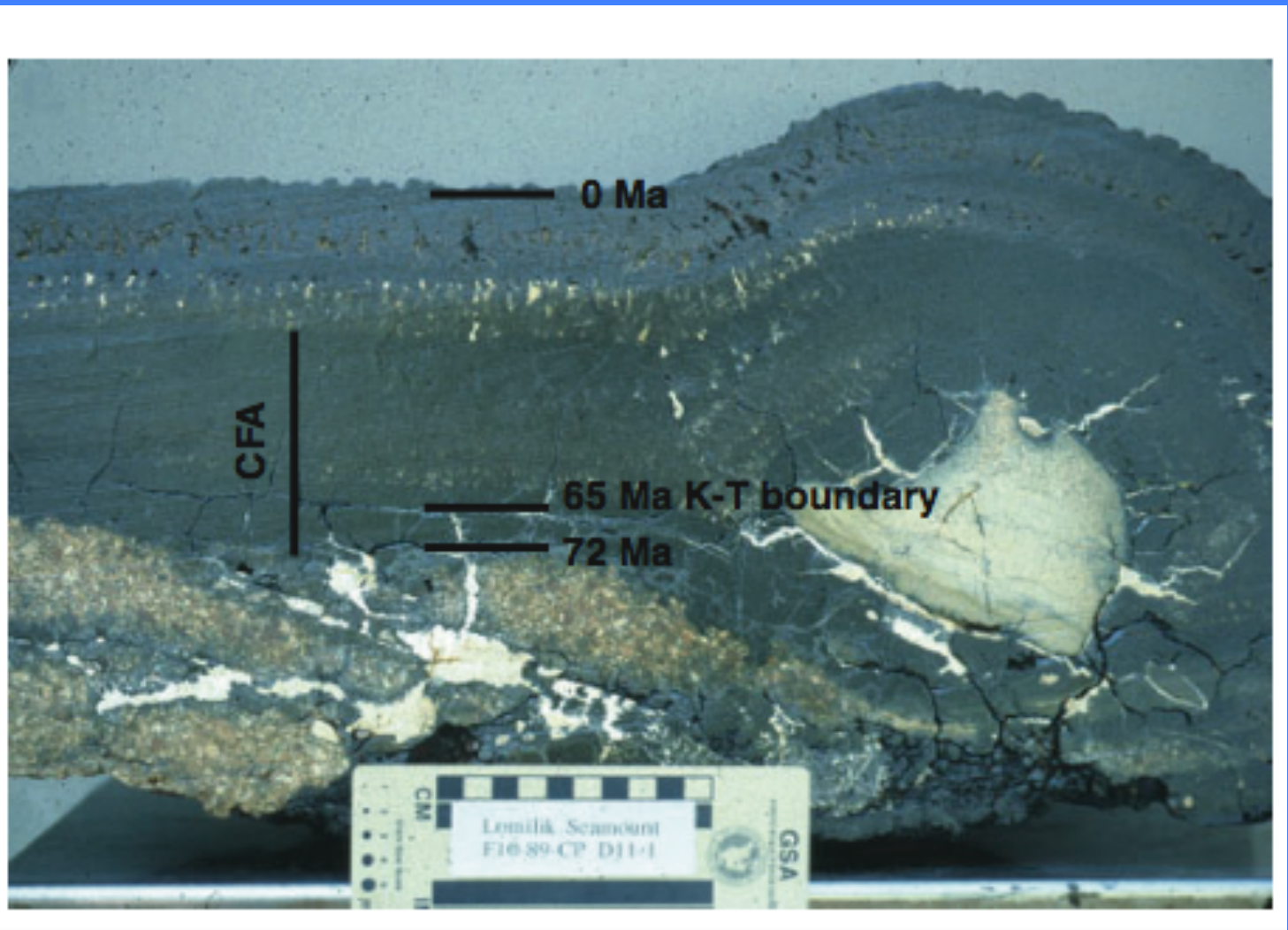
- Very high porosity (60%)
- Extremely high specific surface area (mean 325 m^2/g)
- Incredibly slow rates of growth (1-5 mm/Ma)

** These properties are instrumental in allowing for surface adsorption of large quantities of metals from seawater*

Ferromanganese crust pavement at 2000 m water depth



18 cm-thick ferromanganese crust began growing 72 Ma ago, Marshall Islands



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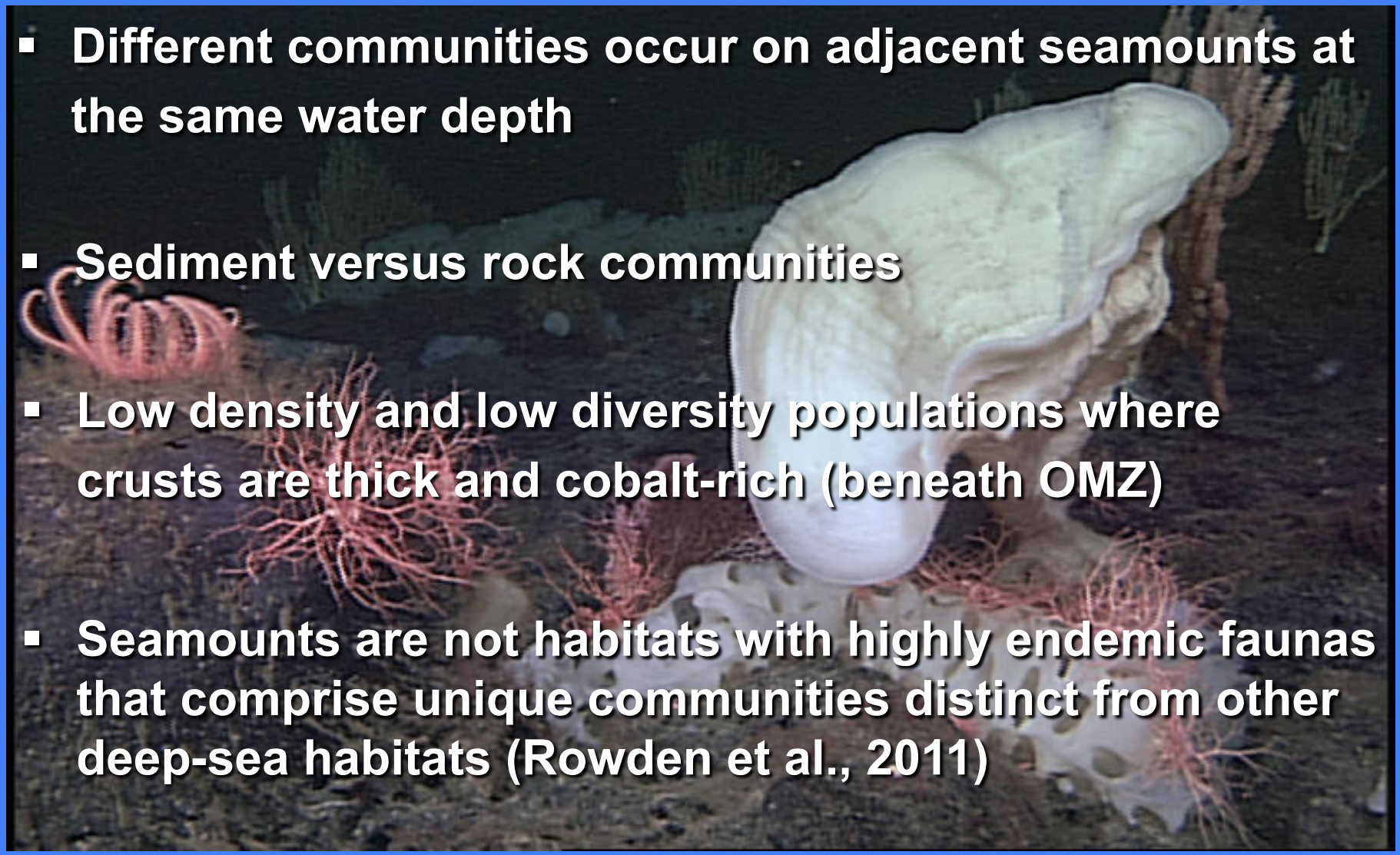
Seamount Biology



- Different communities occur on adjacent seamounts at the same water depth
- Sediment versus rock communities
- Low density and low diversity populations where crusts are thick and cobalt-rich (beneath OMZ)
- Seamounts are not habitats with highly endemic faunas that comprise unique communities distinct from other deep-sea habitats (Rowden et al., 2011)

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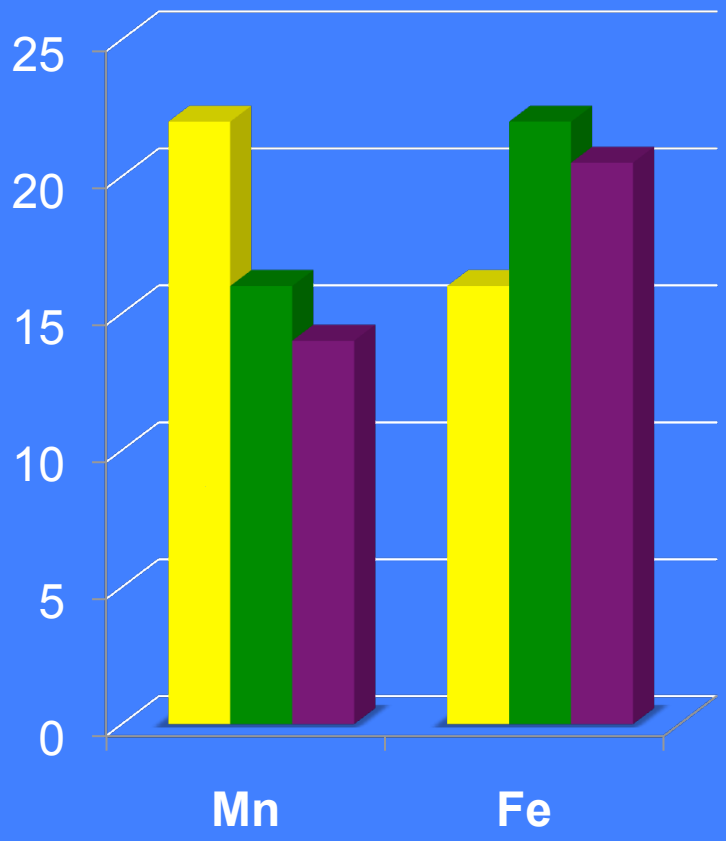
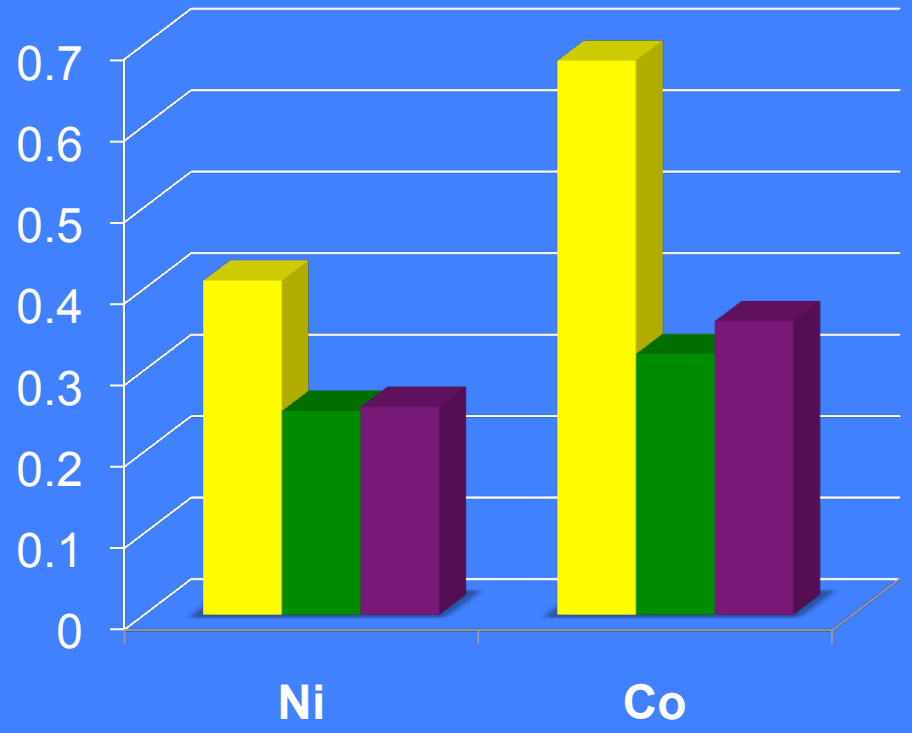
Crusts in the Global Ocean (wt %)



Pacific Prime

Indian Ocean

Atlantic Ocean



Greatest economic interest for nickel, cobalt, manganese

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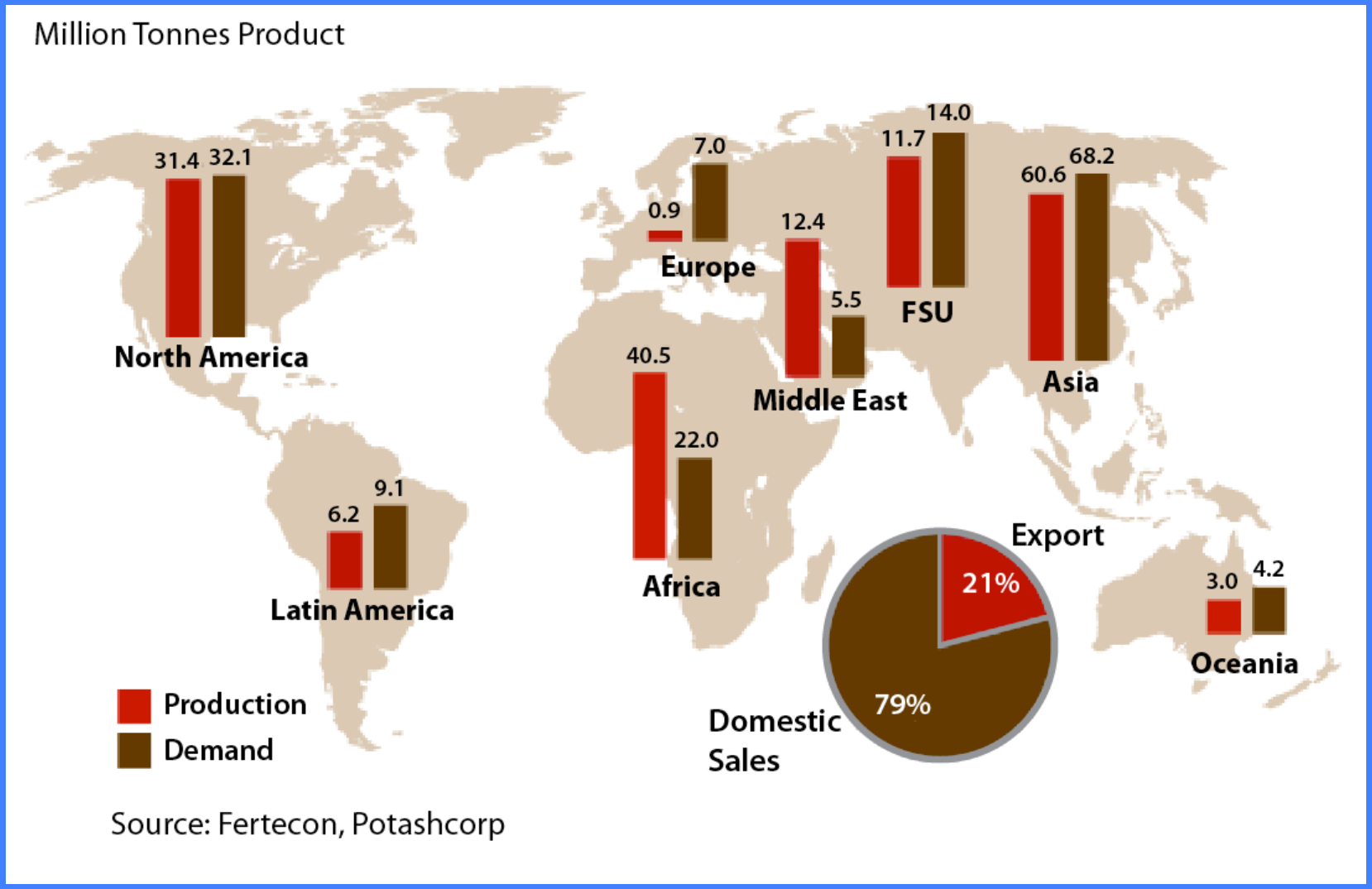
Uses of Phosphate

Phosphate Production and Demand

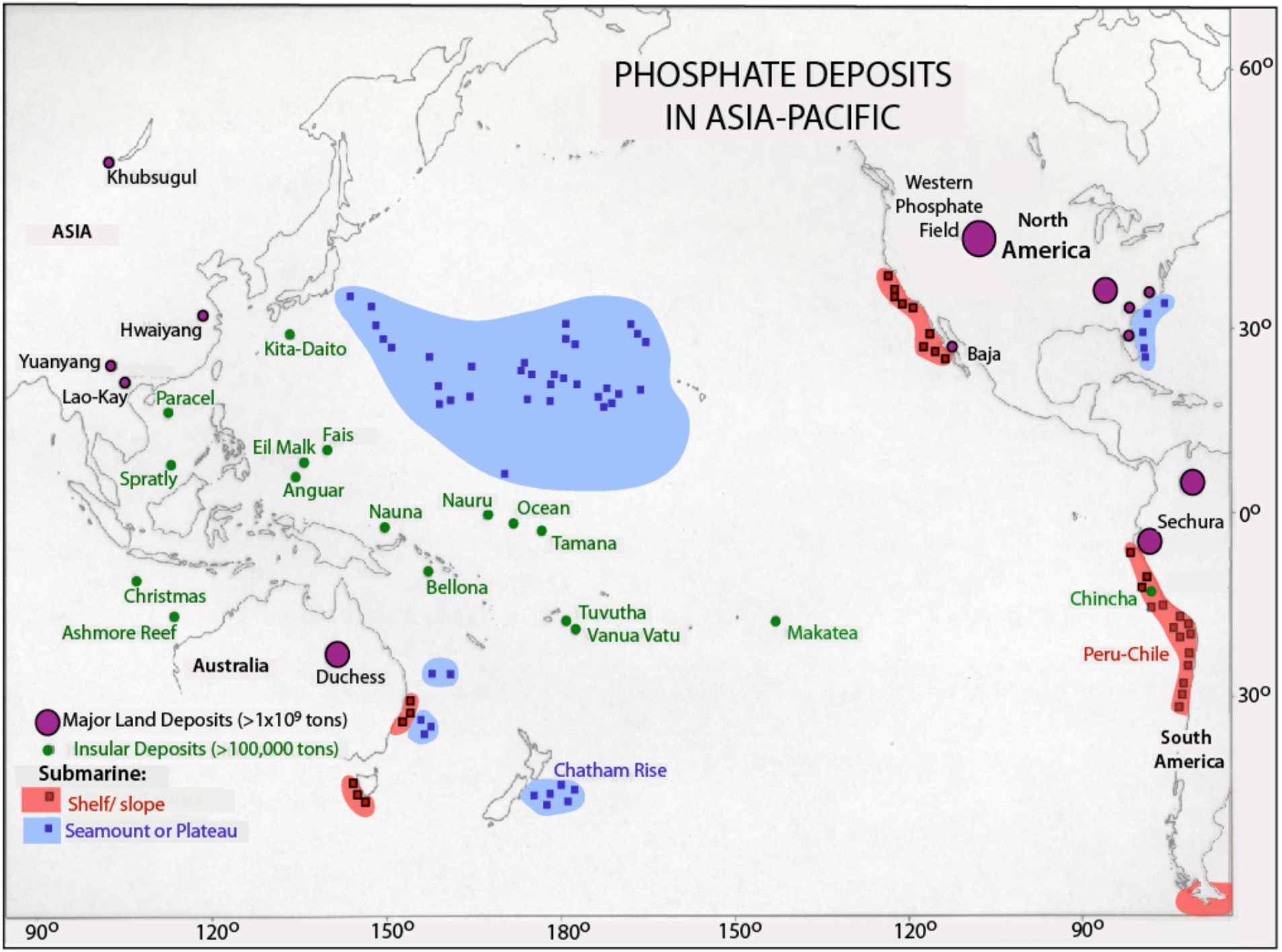


Marine Phosphorite occurs as:

- Seamount and plateau deposits (The Area)
- Insular and lagoonal deposits
- Shelf/slope deposits (EEZs)
- Epicontinental-sea deposits in the land-based geologic record, including giant deposits e.g. Phosphoria Fm (USA)

Seamount Phosphorite deposits

- Occur on most open-ocean Pacific and Atlantic seamounts
- Deposits range from pure phosphorite to those with only minor phosphate minerals
- May provide an additional source of rare-earth elements


PHOSPHATE DEPOSITS
IN ASIA-PACIFIC
Khubsugul
ASIA
Hwaiyang
Yuanyang
Lao-Kay
Paracel
Spratly
Kita-Daito
Eil Malk
Fais
Anguar
Nauna
Nauru
Ocean
Tamana
Bellona
Christmas
Ashmore Reef
Australia
Duchess
Tuvutha
Vanua Vatu
Makatea
Chatham Rise
Western
Phosphate
Field
North
America
Baja
Sechura
Chincha
Peru-Chile
South
America
Major Land Deposits (>1x10⁹ tons)
Insular Deposits (>100,000 tons)
Submarine:
Shelf/ slope
Seamount or Plateau
60°
30°
0°
30°
90°
120°
150°
180°
150°
120°
90°


Thank You