Ocean Exploration Activities in the Arctic - USGS

Ocean Exploration Advisory Board – Fourth Meeting
St. Petersburg, FL
January 20, 2016

Dr. John Haines
Coastal and Marine Program Coordinator
U.S. Geological Survey

U.S. Department of the Interior
U.S. Geological Survey

USGS & OER: Intersection of Interests and Capabilities
Office of Exploration and Research
Strategic Plan Elements for FY 2016-2020

GOAL 1: *Conduct place-based and theme-based ~~ocean exploration to make discoveries~~ **mapping and research programs** that provide scientific, economic, and cultural value--with an emphasis on the U.S. Exclusive Economic Zone and Extended Continental Shelf.*

Objective 1.1: Map and characterize ocean basin features of interest. ✓

Objective 1.2: Discover and characterize geological, physical, chemical, and biological ocean processes and phenomena. ✓

Objective 1.3: Discover and characterize potential ocean resources. ✓

Objective 1.4: Discover and characterize submerged cultural resources in the ocean including shipwrecks, aircraft, and paleolandscapes, ✓

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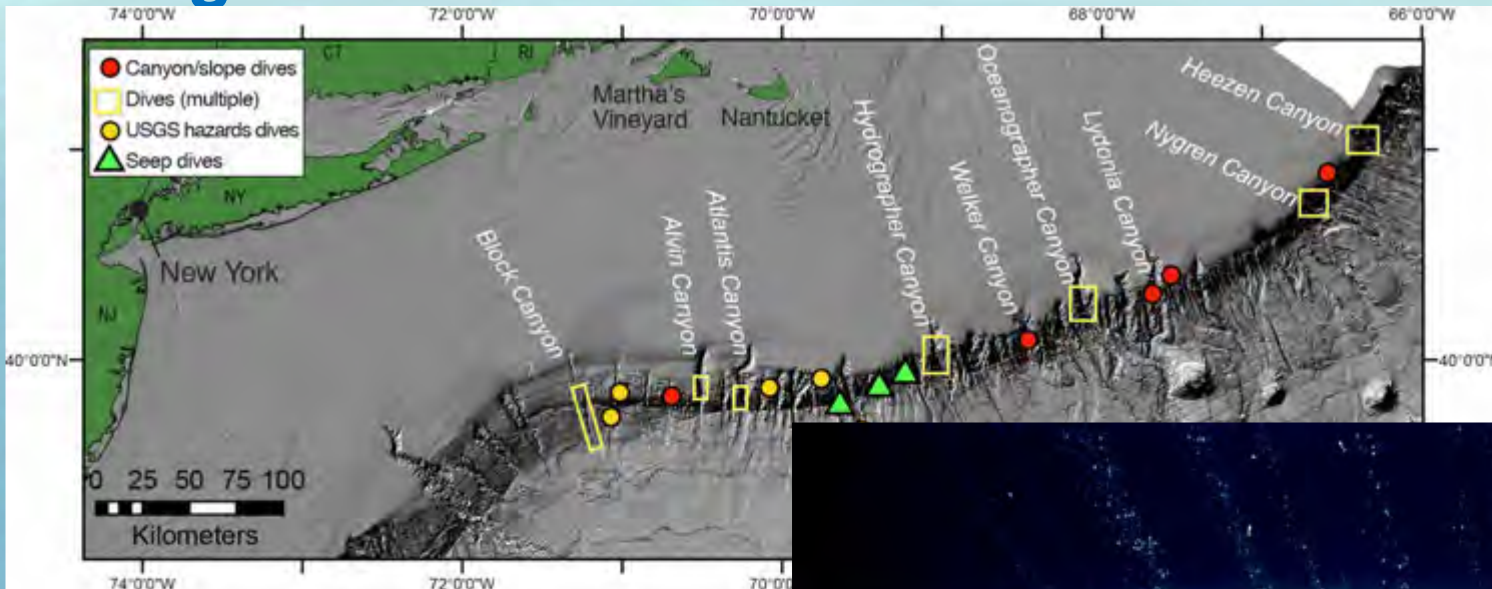
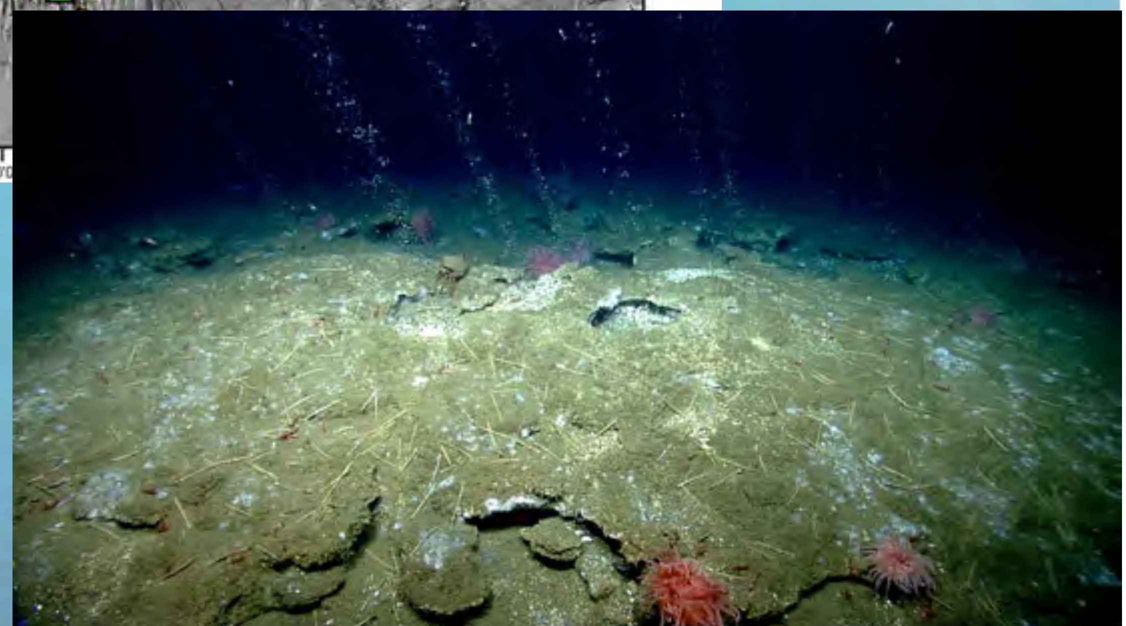
Digression – Exploration and Discovery is integral to Ocean Research





We have objectives, and hypotheses to test, but we're almost always going somewhere new <u>or looking at the system in new ways</u>. We don't know what we'll find – and we are always surprised.

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GOAL 2 *Advance the pace, scope, and efficiency of ocean exploration and discovery through technology innovation*

GOAL 3 *Provide easy and open access to all of the information OER produces*

GOAL 4 *Develop the next generation of ocean explorers, scientists, and engineers*

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GOAL 5: *Build the U.S. National Ocean Exploration Program through planning and exploration partnerships that advance national ocean exploration priorities.*

Objective 5.1: Engage national ocean exploration program stakeholders to identify ocean exploration priorities, needs, and capabilities.

Objective 5.2: Work across federal agencies, non-governmental organizations, and the private sector to encourage coordination of ocean exploration activities where interests intersect.

Objective 5.3: Collaborate with stakeholders to design strategic frameworks for multi-year multi-platform, multi-partner ocean exploration campaigns in priority ocean basins.

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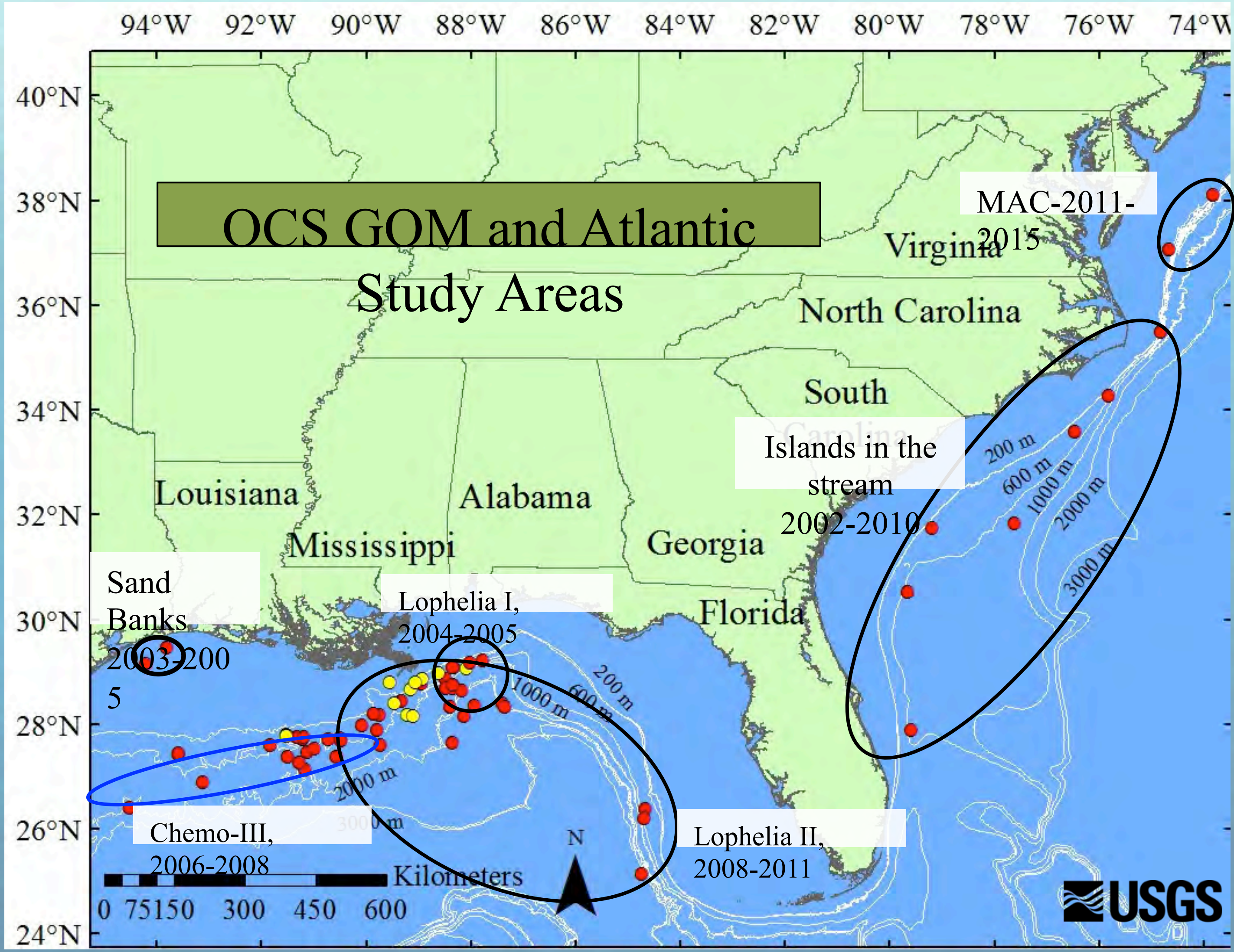
The formal partnerships are only part of the story



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Sharing tools, data, missions, perspective and capabilties – and making connections

USGS and OER: Common Interests, Common Constraints

(from letter to K.D. Sullivan, 2 October 2015

- **The Extended Continental Shelf project should be completed as quickly as possible**
- **Exploration days-at-sea are expensive, every opportunity should be taken to collect samples and measure bio/geo/chemical/dynamics/acoustics phenomena**
- **Creatively pursue partnerships, cost sharing or contracts to reach … requirements.**

USGS

The USGS …. An Introduction

- A natural science and information bureau within the Department of the Interior
- 150+ Years, with Exploration in our DNA

The Organic Act of 1879 (43 U.S.C. 31 et seq)

The Geological Survey is directed to classify the public lands and examine the geological structure, mineral resources, and products within and outside the national domain

Subsequent legislation authorizes a continuing program of ocean research that "shall include…. studies of the ecological, geological, and physical aspects of the deep seabed"

The USGS is the federal science agency providing marine geologic expertise, research and surveys

USGS

The USGS …. An Introduction

- **150+ years later ….. our ocean activities are diverse and organizationally distributed**

USGS Mission Areas that have an Ocean research role/requirement

Ecosystems – support DOI resource management agencies
Climate – paleo-climate/paleo-environmental records
Water
Energy & Minerals – resource understanding/assessments
Environmental Health
Natural Hazards – EQ, tsunami sources for hazard assessment

Coastal and Marine Geology Program
- Supporting all these "Missions", and providing fundamental understanding of marine geologic framework and processes

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USGS – Priorities and Constraints/Challenges

Priorities span multiple missions/programs – responding to national, DOI and other agency needs

Resource competition is fierce – terrestrial and coastal interests >> marine, demands from all "regions"

[We need to make our ocean priorities "their" priorities]

We have no marine research vessels – and limited resources to support marine field programs

Our "priorities" or interests exceed our capacity … so we partner and leverage in setting priorities, planning, and execution.

We rarely "go alone", when we "go together" we bring world-class scientific expertise and capabilities.

We've benefited from working with OE, and OE has benefited from our mission, expertise, and productivity.

USGS

So, what does this mean for the USGS in the Arctic?

The USGS …. The Arctic

- **Access to marine environments is a challenge – particularly in the Arctic (the right tools are required).**
- **The Arctic ECS was an absolute and multi-year priority, leaving other regions "wanting" for major marine field programs.**
- **Every opportunity to leverage the very targeted ECS objectives to broader mission objectives was seized.**
- **The Arctic is an unexplored frontier for investigations of marine communities, climate change and environmental health, and mineral resources – and will require collaborative efforts – much like those of USGS, NOAA, BOEM, DOE and others along the Atlantic Margin in recent years.**
- **Studies of methane/gas hydrate "systems" , spanning programs and missions, is a high priority for collaborative field programs in the Arctic, building upon successes in the Atlantic (and fantastic prior work in the Arctic).**

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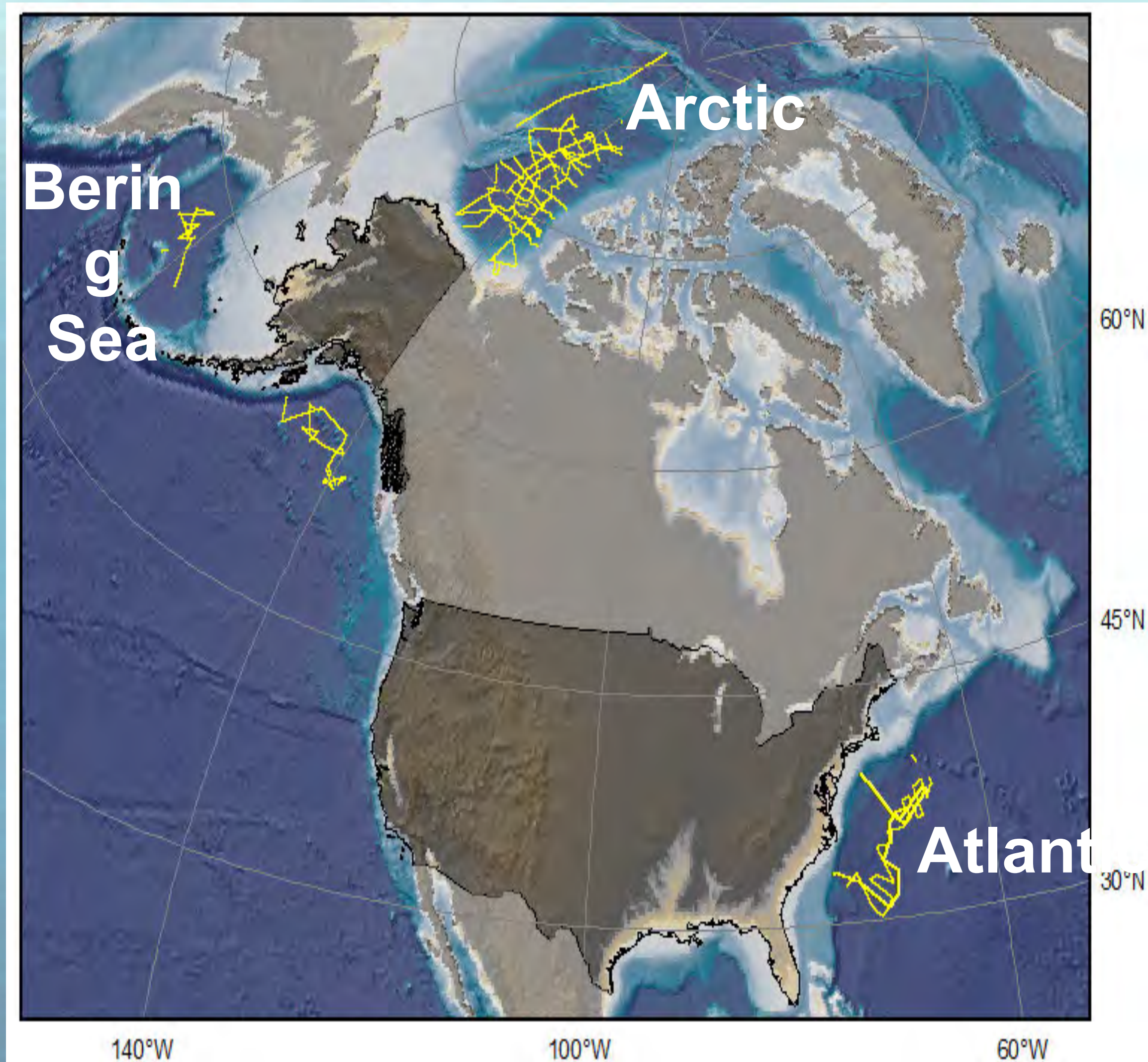
USGS ECS Data Acquisition
Collaborative with NOAA/UNH



USGS Role
- Geology & science interpretation
- Seismic data
- Determine sediment thickness

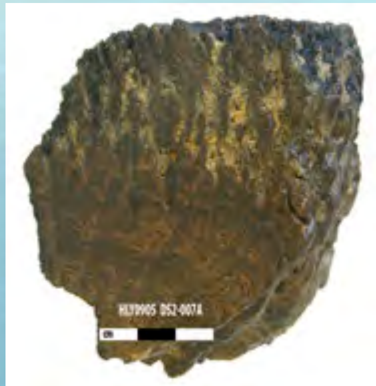
NOAA Role
- Seafloor bathymetry
- Information Management
- Determine morphology

DOS Role
- ECS Project Management
- Legal issues
- Final Documentation

USGS

Arctic Exploration and Arctic Minerals

Dredging by NOAA/UNH Healy



Rare Metals in low-cobalt Crusts:

Arsenic, Lithium, Nickel, Scandium, Vanadium, Zirconium, Rare Earth Elements

Rare Metals in high-cobalt Crusts:

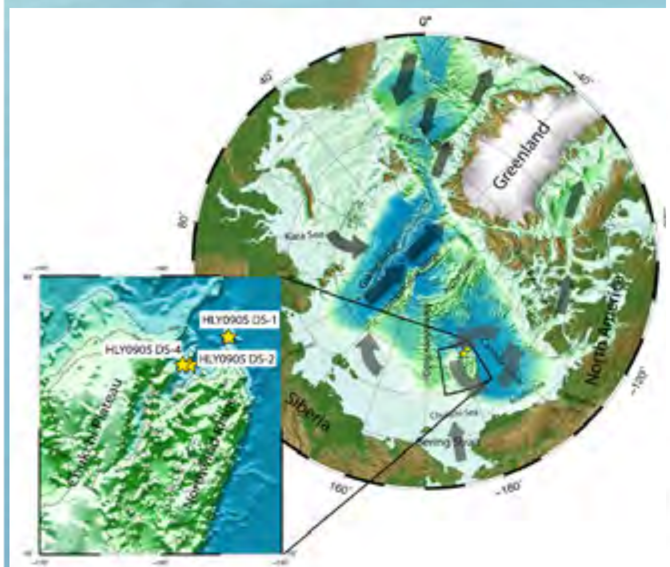
Arsenic, Cobalt, Lithium, Molybdenum, Nickel, Scandium, Thorium, Zirconium, Rare Earth Elements

Rare Metals in Nodules:

Arsenic, Cobalt, Lithium, Molybdenum, Nickel, Vanadium, Zirconium, Rare Earth Elements

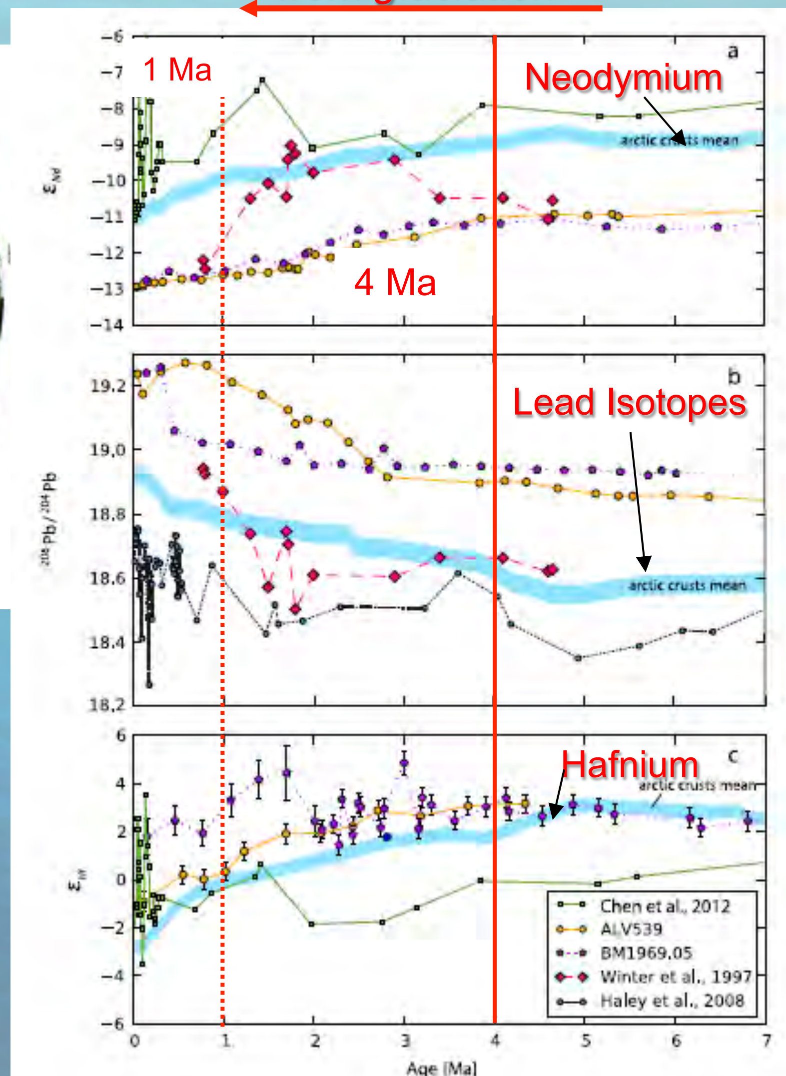
- The mineral resource potential of the Arctic ocean is not known, but is likely to be vast. USGS studies since 2010 are the first to show that Arctic Ocean mineral deposits in the potential U.S. ECS are significantly enriched in metals of importance to military, high technology, green technology, and energy applications.
- These important mineral deposits within our potential ECS warrant further evaluation.

Arctic Exploration, Minerals, and Climate
Dredging by NOAA/UNH Healy HE-0905



Sample Sites

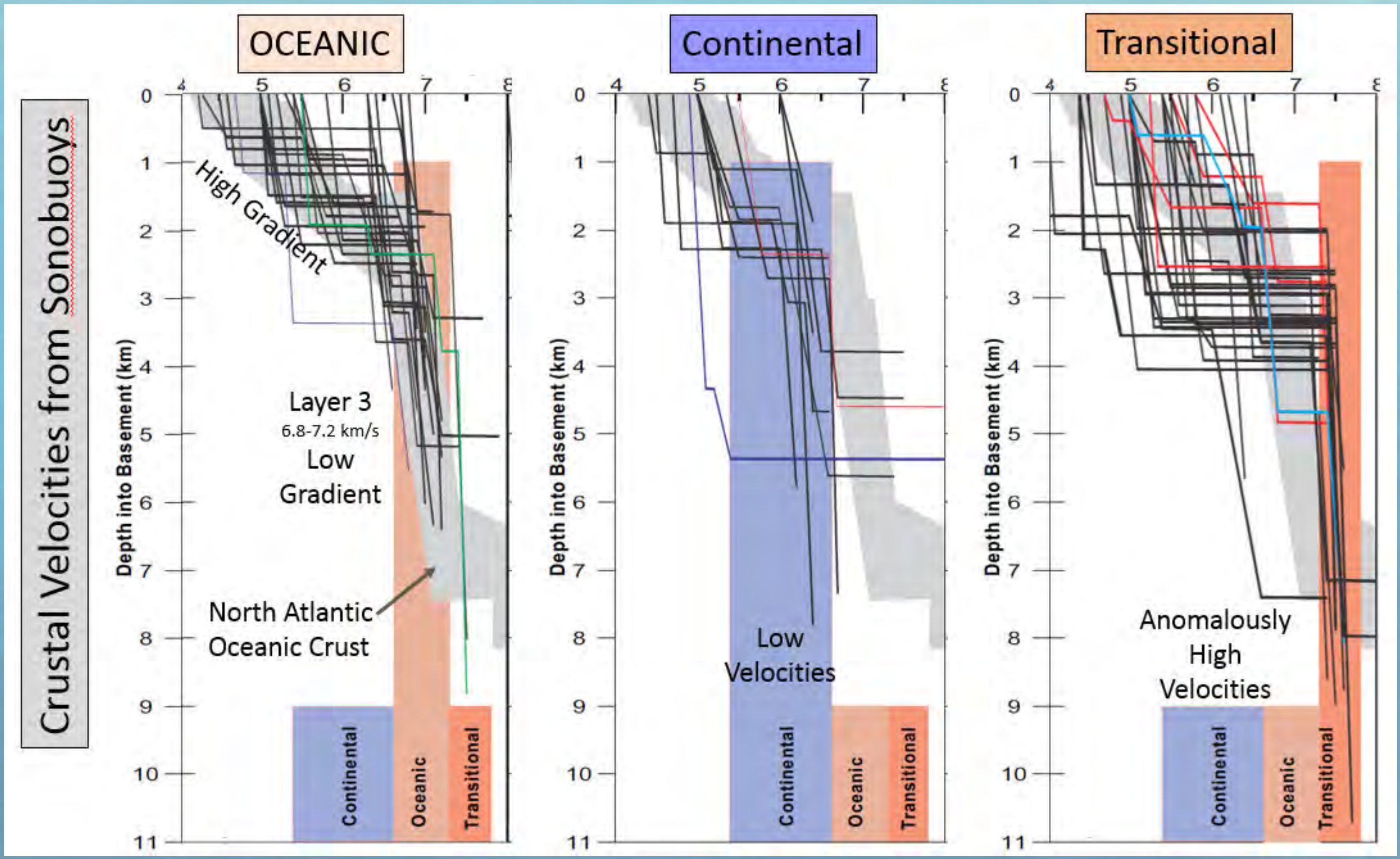
Increasing weathering inputs from glaciation



Three radiogenic elements from dated Fe-MN crusts from northern Chukchi Borderland were analyzed. Results show smoothly varying trends in these elements that are interpreted to be caused by increasing effects of glaciation through the past 4 Ma. These trends are representative of changes in Arctic Deep Water for the past 7 Ma. These results are in contrast to results for Arctic Intermediate Water, and suggest that even larger differences between these two water bodies existed in the past.

Arctic Exploration and Evolution of the Canada Basin

One of the many debates about the origin of the Canada Basin north of Alaska is whether oceanic crust fills the entire basin or only part of the basin. Sonobuoy velocity measurements, coincident with multichannel seismic data show three crustal types actually exist in the deep basin, distinguished by their velocities:



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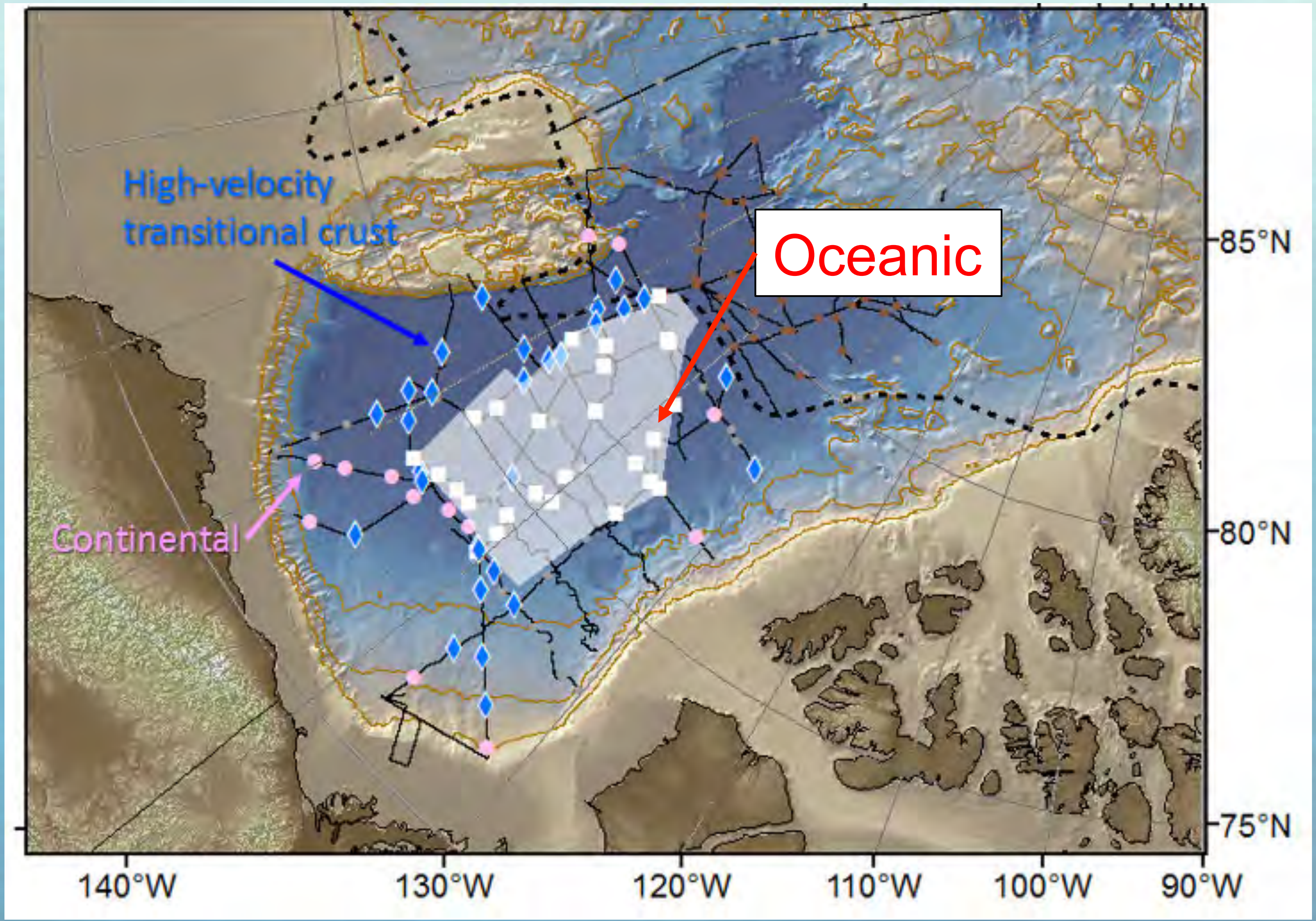

Oceanic crust is restricted to the central portion of the Canada Basin. The size and shape of the oceanic polygon are consistent with previously proposed rotational opening. BUT the existence of continental crust so far north of the Alaskan margin and in deep water off the Canadian Arctic margin (pink dots) are new challenges to explain.

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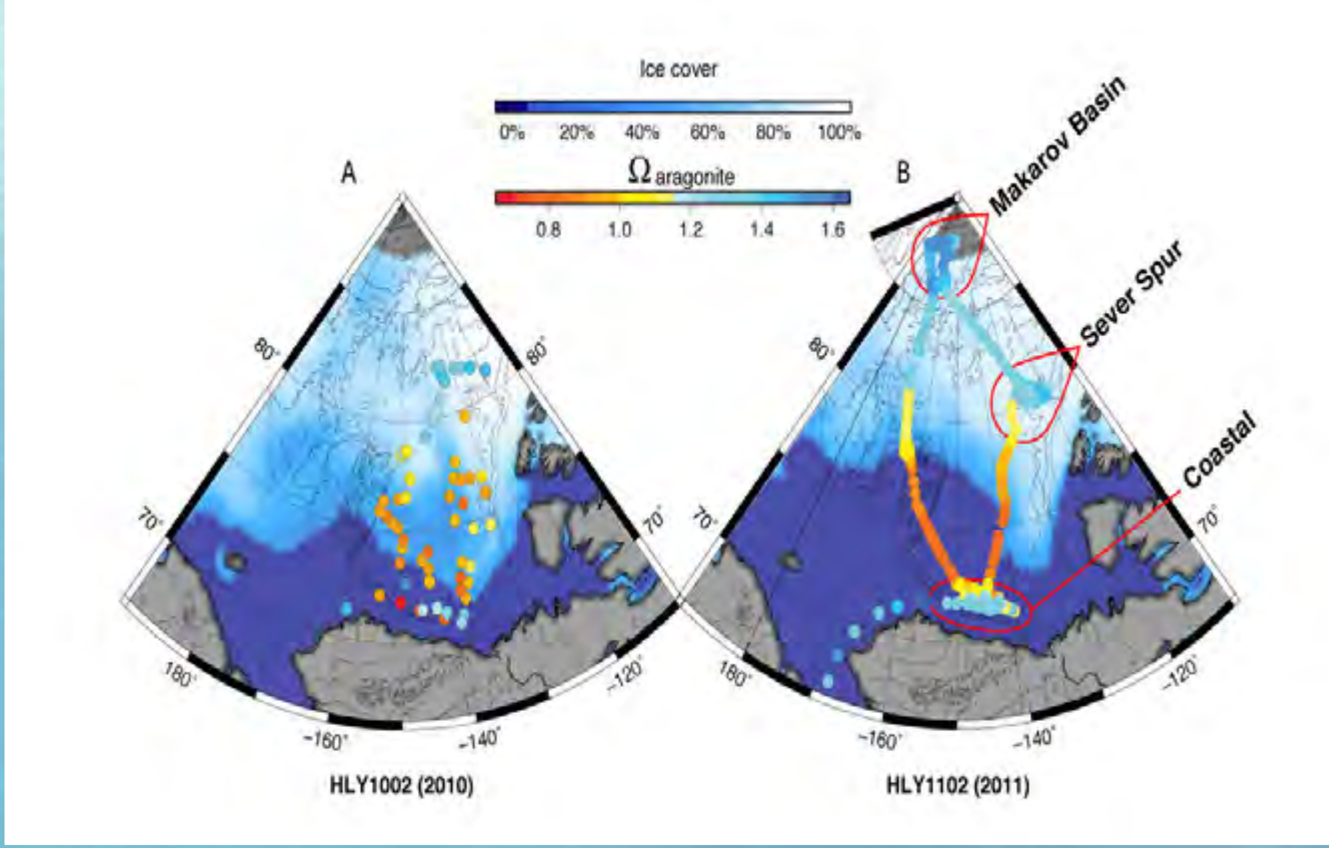
Ocean Acidification

Underway marine and atmospheric sampling



- **Atmospheric CO2, ice cover, freshening of the water, warming and terrestrial inputs all control ocean acidification in the Arctic Ocean.**
- **Ocean acidification in the Arctic will influence some nutrient cycling and trace metal speciation.** *Forms of calcium carbonate will become geochemically unstable in the next decades.*
- **Major knowledge gaps on ecological interactions and individual species response through acclimation and adaptation exist.**

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The USGS …. Arctic (Ocean) interests looking ahead

USGS Mission Areas

Ecosystems – impact of energy activities and climate change on ecosystem health, DOI managed wildlife, native communities, and benthic community occurrence/vulnerability/health

Climate – paleo-climate/paleo-environmental records, climate drivers and landscape change

Energy & Minerals – resource understanding/assessments, gas hydrate systems (energy resource)

Environmental Health – cycling and accumulation of toxic substances, impacts on wildlife and humans

Coastal and Marine Geology Program
- Changing Ocean Geochemistry/Ocean Acidification, methane/gas hydrate systems (geologic/marine/atmospheric) and global climate change, geologic characterization and processes

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A “system” focus – the Arctic Methane system

How could it affect climate? How prevalent are gas hydrates, methane seeps and seep communities? How could changes in the hydrate system alter ocean geochemistry and impact benthic and water column communities? What is the role of hydrates in benthic structure and slope stability?

NOAA OER has contributed to a tremendous advance in our knowledge of the distribution of hydrate seeps, communities and the associated geologic framework and hazards along the Atlantic Margin. “Discovery” resulted, including from new observational methods – and our understanding of methane systems has been advanced, overturned, and presented with new challenges. We exposed huge gaps in our knowledge through collaborative work along the Atlantic Margin – but the Arctic is where we really need to be.

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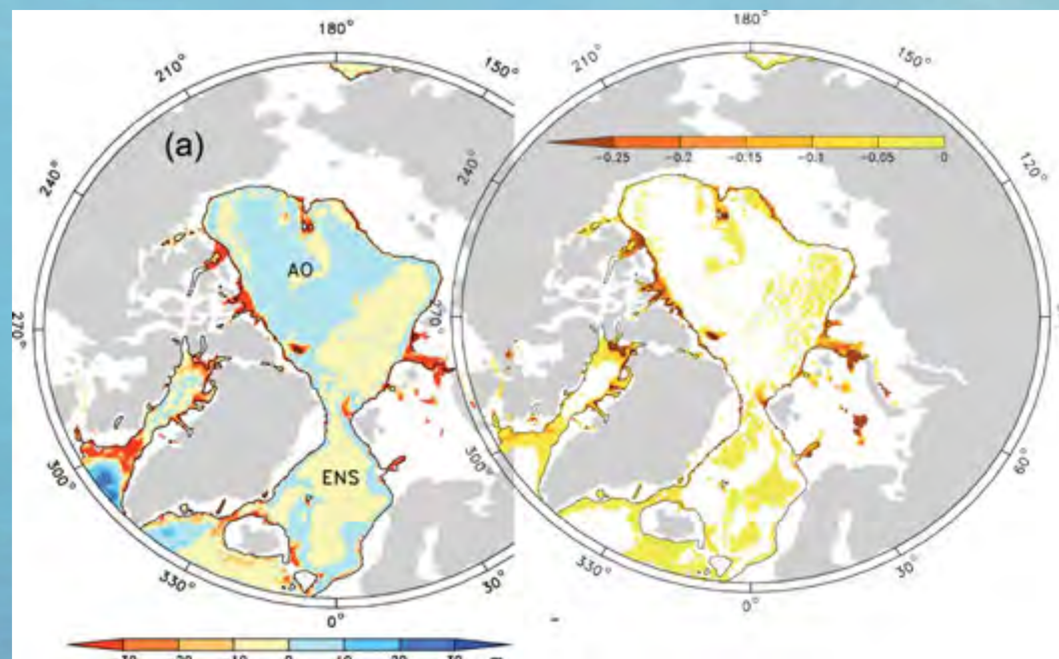
Methane in the atmosphere is ~20 times more potent than CO_2 as a greenhouse gas.

How will Arctic methane hydrate be affected by continued climate warming?

- Sea-level rise stabilizes gas hydrates
- Warming air and ocean temperatures contribute to permafrost thaw and gas hydrate breakdown and overwhelm stabilizing effects of sea-level rise
- "Runaway" breakdown (dissociation) of gas hydrates not possible; endothermic heat of dissociation shuts down dissociation

Hydrate changes

pH changes (acidification)



Biastoch et al., 2011

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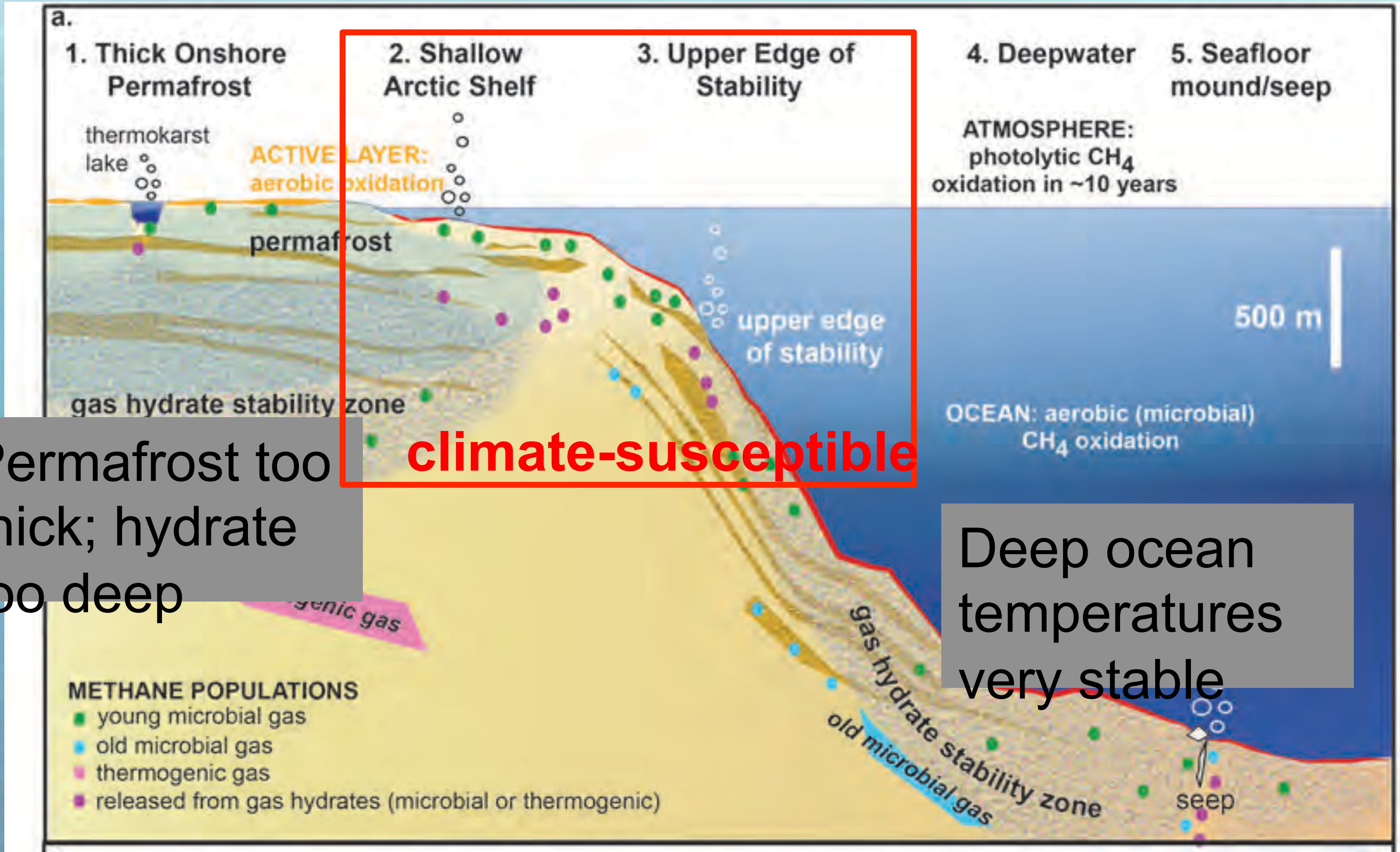
Types of Gas Hydrate Deposits

global
Arctic



Permafrost too thick; hydrate too deep

Deep ocean temperatures very stable

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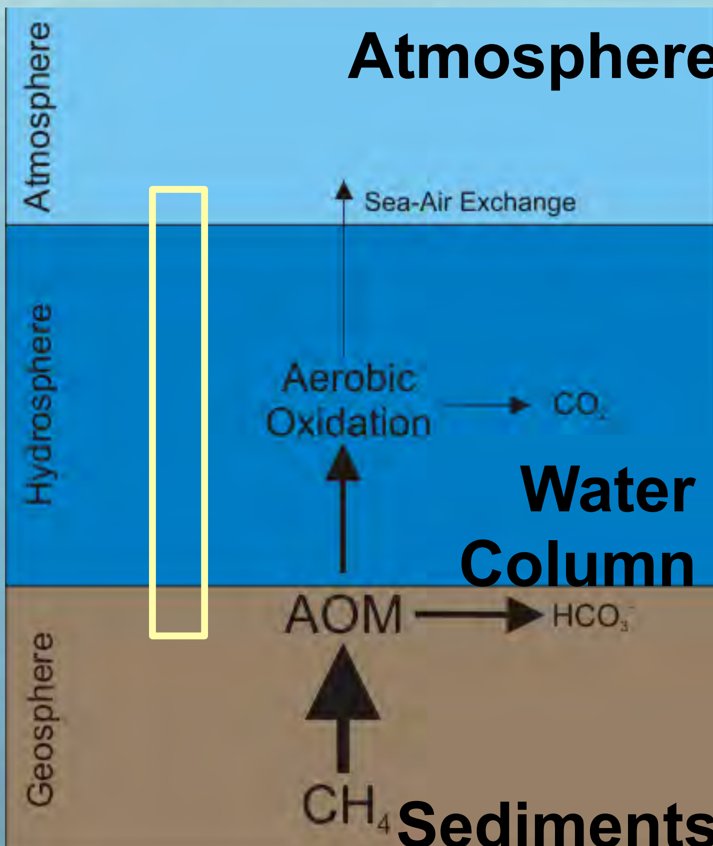
Ruppel, *Nature Knowledge*, 2011

Carbon Cycle: Sources and Sinks from below Seafloor to Sea-Air Interface

METHANE MEASUREMENTS



Methane sources
Methane concentration

↑ ***Methane flux***

Methane production
Methane oxidation to CO_2 and consequent acidification
Dissolved methane/methane bubbles

↑ ***Methane flux***

Methane sink (anaerobic methane oxidation)
Methane production
Amount of hydrate and gas

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Challenge: Distinguishing methane released by gas hydrate from other methane (e.g., noble gas fingerprinting?)

We estimate there are tremendous volumes of methane/carbon sequestered in Global Gas Hydrates (double known natural gas reserves)

Where it is, and how susceptible it is to release – and what happens then – are poorly known

The prevalence of active seeps, associated communities and the affects of changing or variable methane dissociation on the marine ecosystem is largely unknown.

We have the tools to “explore” in time and space, as a integral part of a broad Arctic ocean exploration program.

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USGS Role in Deep-Sea Minerals Assessment

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The USGS: Deep-Sea Minerals' Role

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30 U.S.C 1601 et seq "The Mining and Minerals Policy Act of 1970" and "Minerals Policy, Research and Development Act of 1980" reemphasize the USGS's responsibility to assess the mineral resources of the Nation

USGS

The USGS: Deep-Sea Minerals' Role

30 U.S.C 1419 et seq "The Deep Seabed Hard Mineral Resources Act of 1980" provides for a continuing program of ocean research that "shall include the development, acceleration, and expansion, as appropriate, of the studies of the ecological, geological, and physical aspects of the deep seabed in general areas of the ocean where exploration and commercial development are likely to occur …". The USGS provides geological and mineral resource expertise in responding to the requirements of the Act.

The USGS, as a science agency, is not responsible for regulation or leasing of deep-sea mineral resources and associated activities. USGS provides research and assessment products in support of BOEM's management mission.

USGS

The USGS: Deep-Sea Minerals's Role

The USGS Coastal and Marine Geology Program is the provider of federal science for understanding and assessing deep-sea mineral resources.

Maintaining the nation's research expertise in deep-sea minerals is a core capability and responsibility of the USGS. For the past several decades that capability has been supported at an extremely modest level – reflecting Administration and Congressional interest/support.

Our small, but world-recognized staff, have maintained extraordinary scientific productivity with modest resources – and are regularly called upon to advise on national and international policy.

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USGS: Deep-Sea Minerals

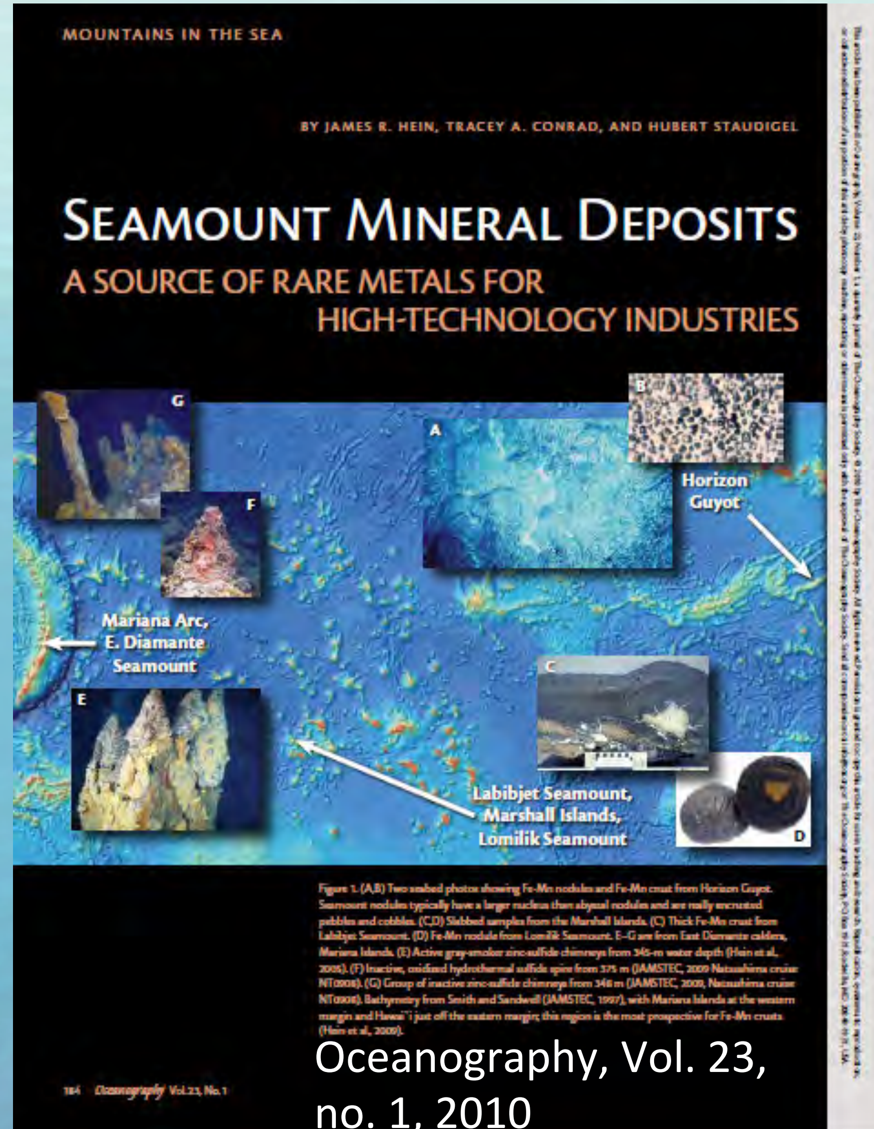
HISTORY

Late 1960’s – USGS marine geology program begins with focus on energy and mineral resources

Mid-1970’s – manganese nodules as research target

1980s – additional focus on cobalt-rich Ferromanganese Crusts and sea-floor massive sulfides (SMS)

Late-1980’s onward – research on hydrothermal manganese deposits and critical and rare-earth elements in all deep-sea mineral types



Oceanography, Vol. 23, no. 1, 2010

Late 70’s-80’s – discovery, exploration and research for SMS in Pacific ridge and fracture zones with NOAA

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USGS Deep-Sea Minerals

Context:

Demand for mineral resources, particularly those rare and critical elements required for high-tech and green industries is expanding rapidly.

Economic health and growth, and economic and national security requires secure and economically recoverable resources

The Deep Ocean hosts substantial deposits of critical minerals – Are they economically recoverable? What are the technological and environmental requirements?

Where? How much? In what forms/complexes?

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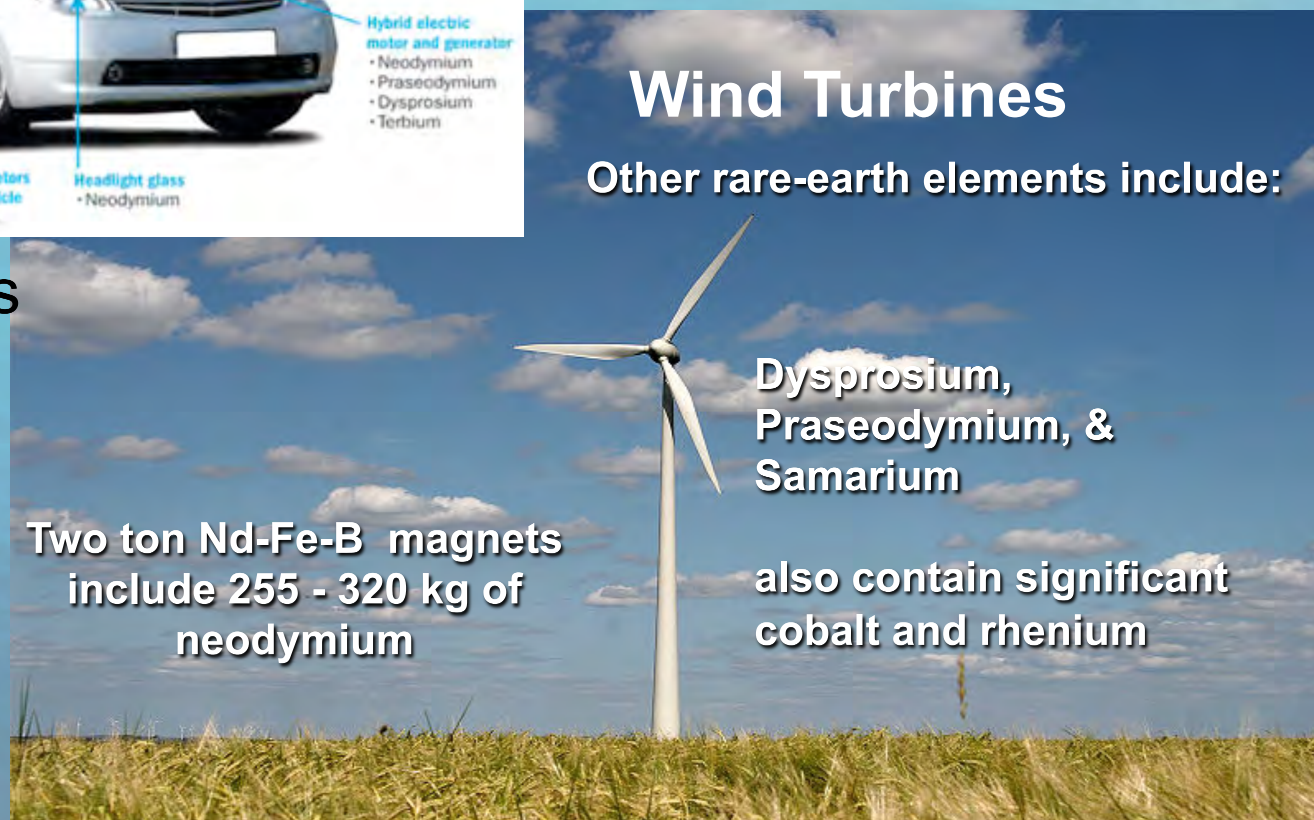
Increasing Demand for REEs

Hybrid Automobiles



Wind Turbines

Other rare-earth elements include:

Dysprosium, Praseodymium, & Samarium

also contain significant cobalt and rhenium

Two ton Nd-Fe-B magnets include 255 - 320 kg of neodymium

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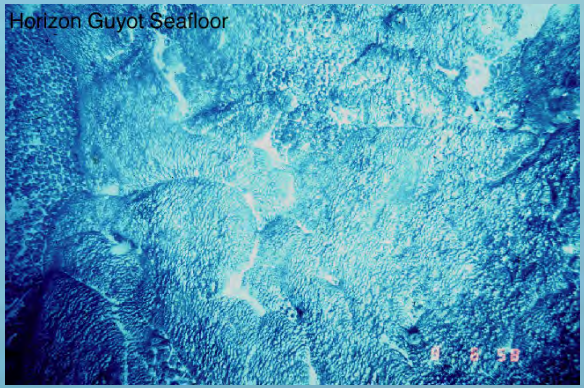
What are the deep-ocean mineral deposits



Manganese nodules

- **Form on the vast deep-water abyssal plains**

Ferromanganese crusts

- **Form on 10^4s seamounts**

Seafloor massive sulfides

- **Form at hydrothermal vents along 89,000 km of ridges**

Phosphorite

- **Form in shelf to deep-water environments**

REY-rich muds

- Form on abyssal plains

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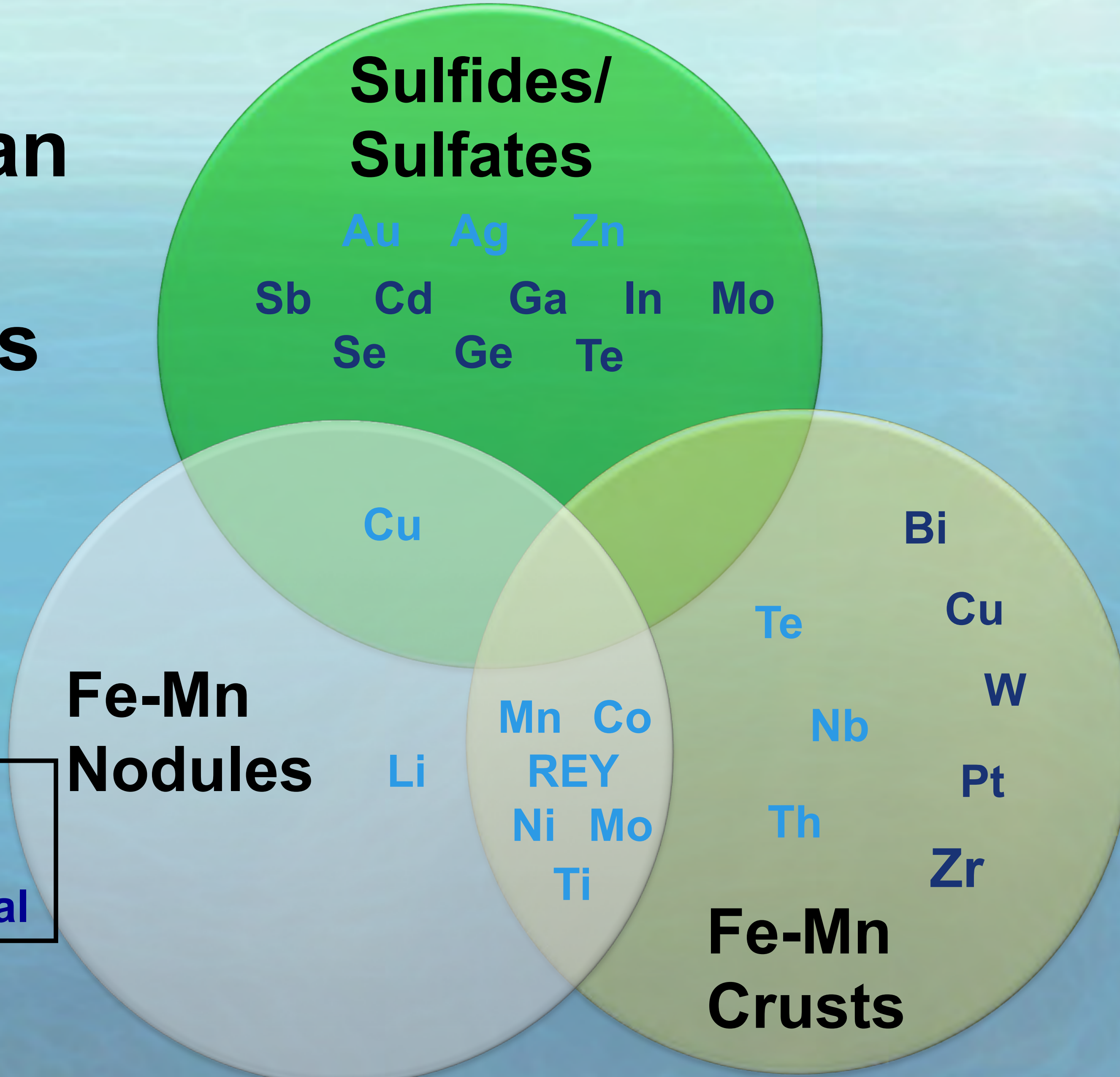
Potential Deep-Ocean Metal Resources



KEY
Good Potential
Longer-Term Potential

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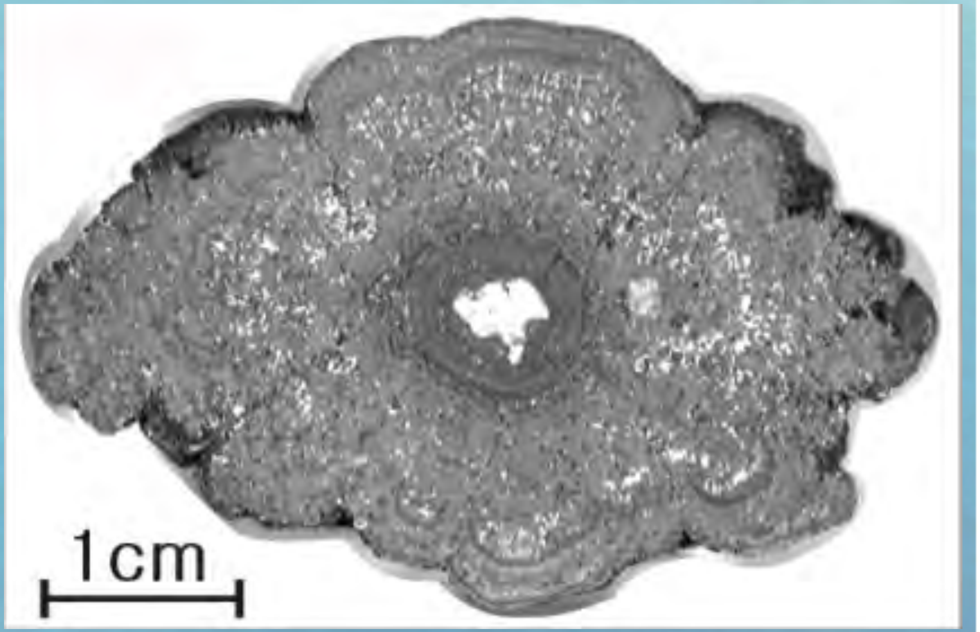
Manganese Nodules

•Form on sediment-covered abyssal plains (4000-6500 meters water depths)

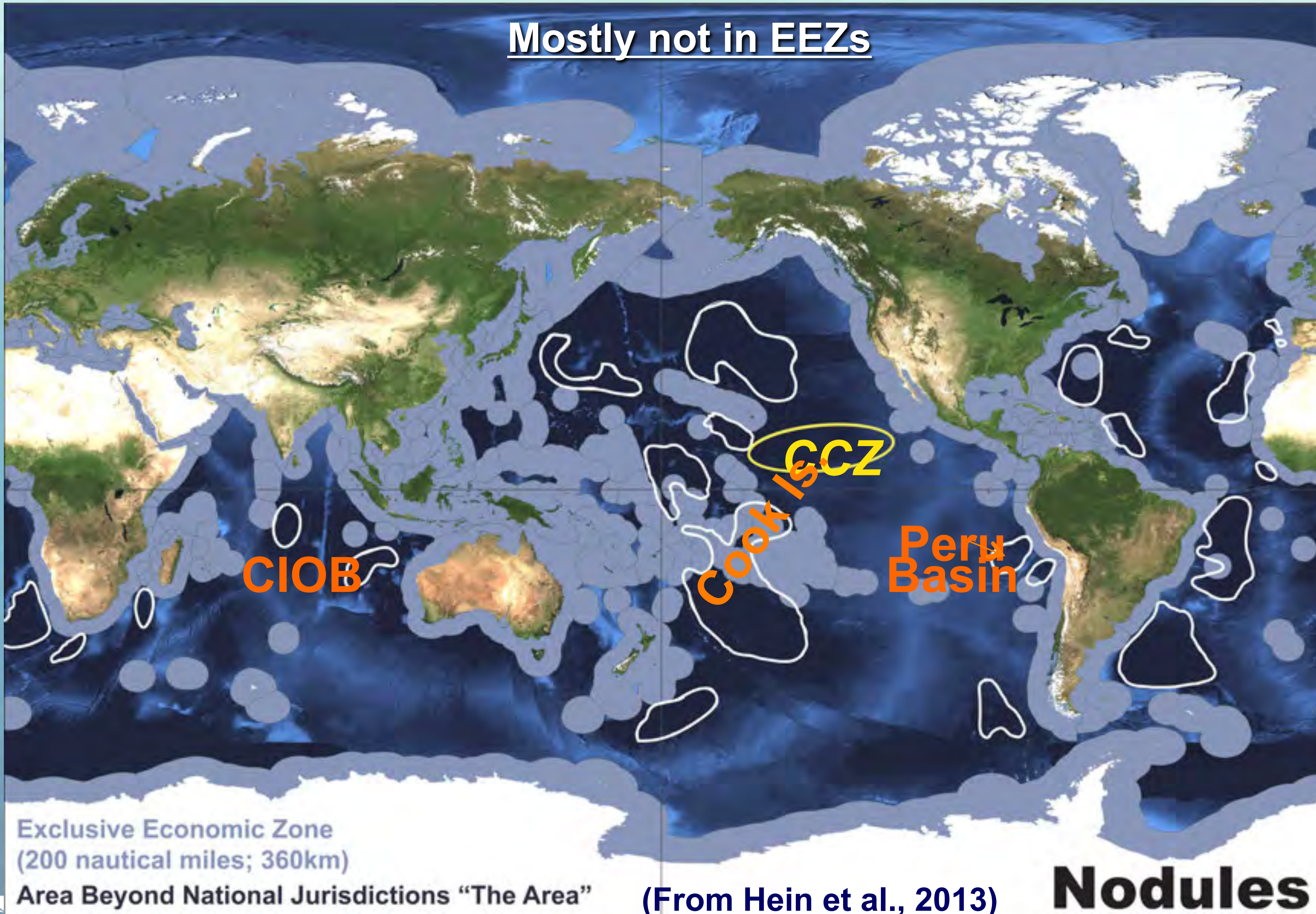
•Composed of manganese and iron oxides, with significant amounts of nickel & copper



•Form by precipitation of metals from cold bottom <u>seawater and sediment pore fluids</u>

•Form in areas with very low sedimentation rates

Global Permissive Areas for Manganese Nodules



Four nodule fields are well known: CCZ, CIOB, Peru Basin, Cook Is EEZ

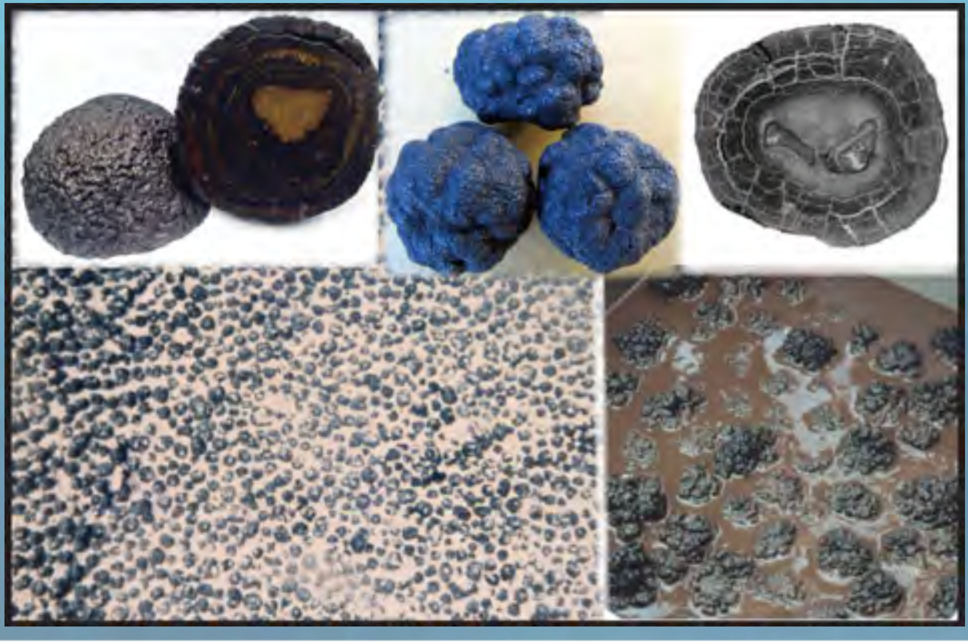
Potential Polymetallic Nodule Ore Deposits

CCZ: Nickel, Manganese, Copper, Molybdenum, Cobalt

CIOB: Nickel, Manganese, Copper, Molybdenum, Zirconium

Peru Basin: Manganese, Nickel, Lithium

Cook Islands: Manganese, REY, Cobalt, Titanium, Nickel



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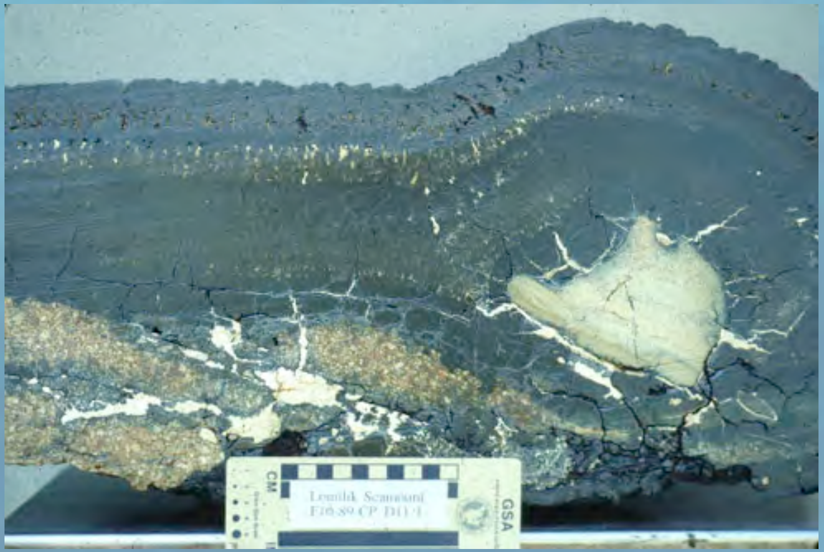
Ferromanganese Crusts

- Grow on hard-rock surfaces on seamounts, ridges, and plateaus
- Found at water depths of ~400-7000 meters
- Thicknesses range from <1 to ~260 millimeters
- Metals precipitate from cold seawater
- Focus metals: Cobalt, Nickel, Manganese



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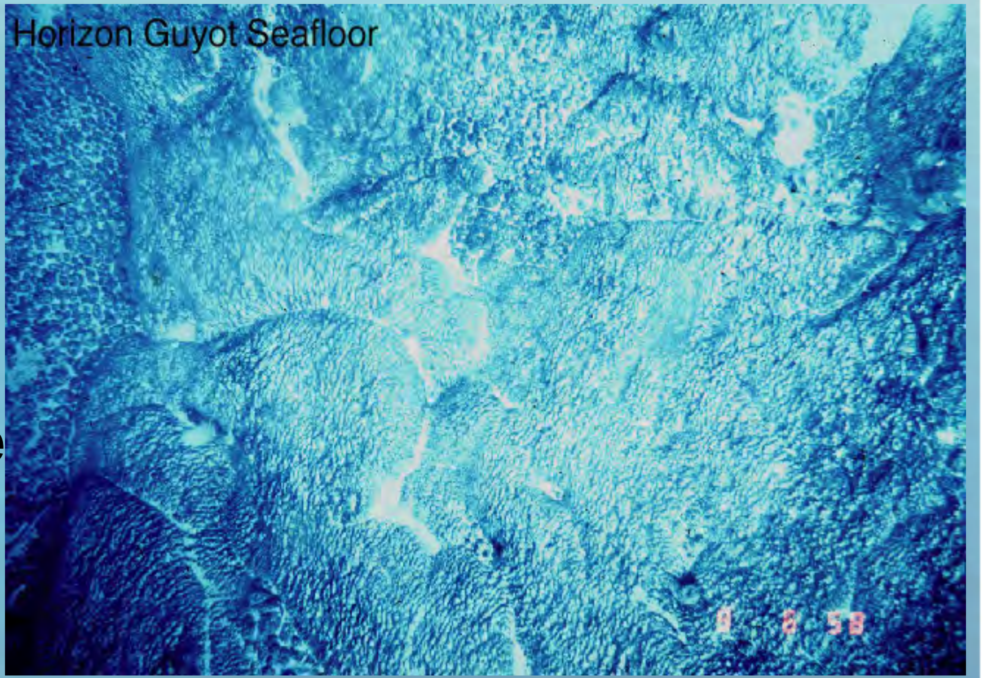
Distribution of Ferromanganese Crusts

- Arctic to Antarctic on seamounts, ridges, and plateaus
- Thickest crusts occur between water depths of 1500-2500 m, the area of the outer summit rim of guyots (flat top seamounts)
- Most cobalt-rich at ~800-2200 m water depths



Fe-Mn crust pavement at 2000 m water depth

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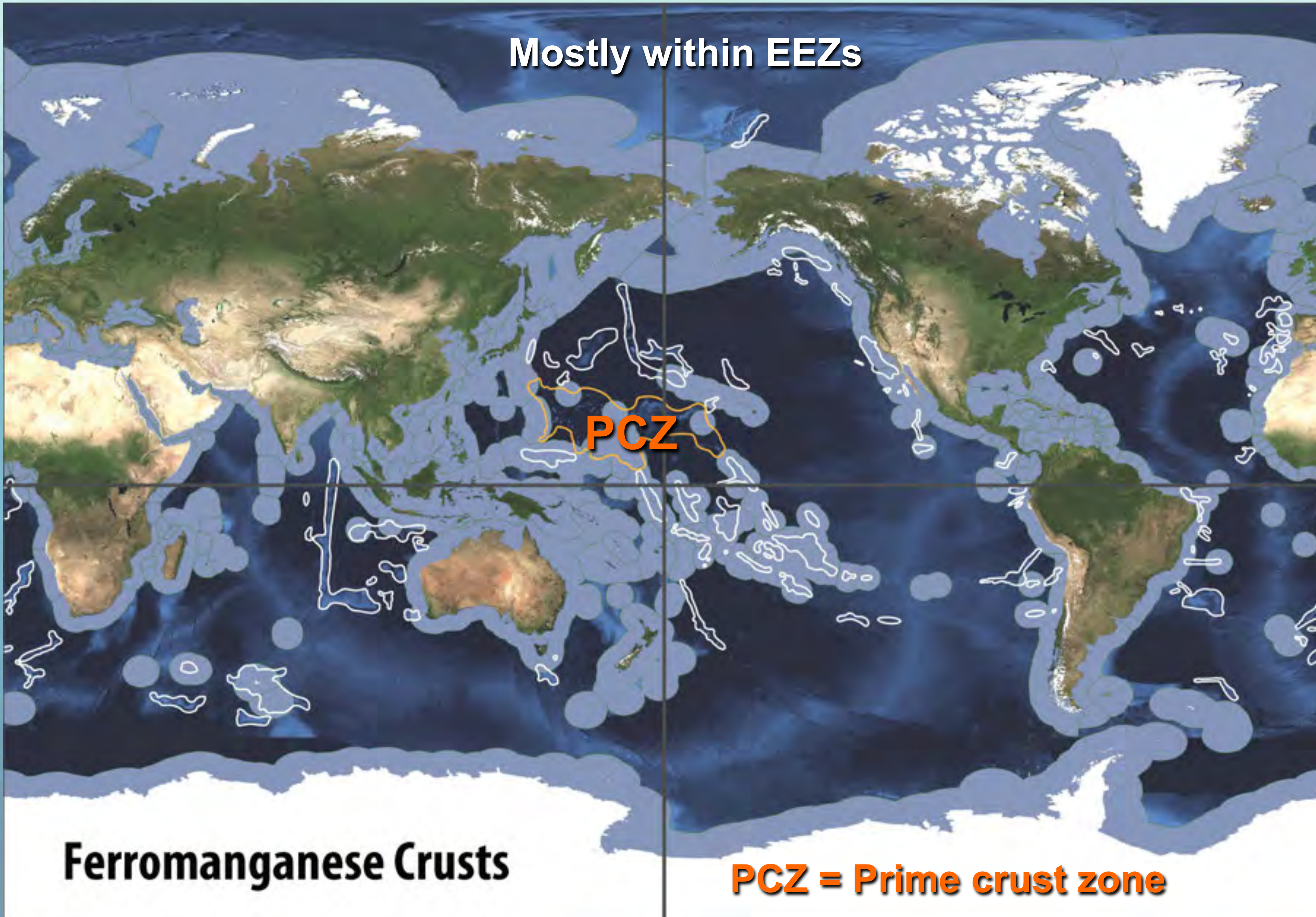
Global Permissive Areas for Ferromanganese Crusts



[From Hein et al., 2(

Rare Metals in Ferromanganese Crusts as Potential Byproducts of Cobalt, Nickel, & Manganese Mining

Rare Earth Elements + Yttrium
Bismuth
Niobium
Molybdenum
Platinum
Scandium
Tellurium
Thorium
Titanium
Tungsten
Zirconium

Scandium-rich crust from the Arctic Ocean

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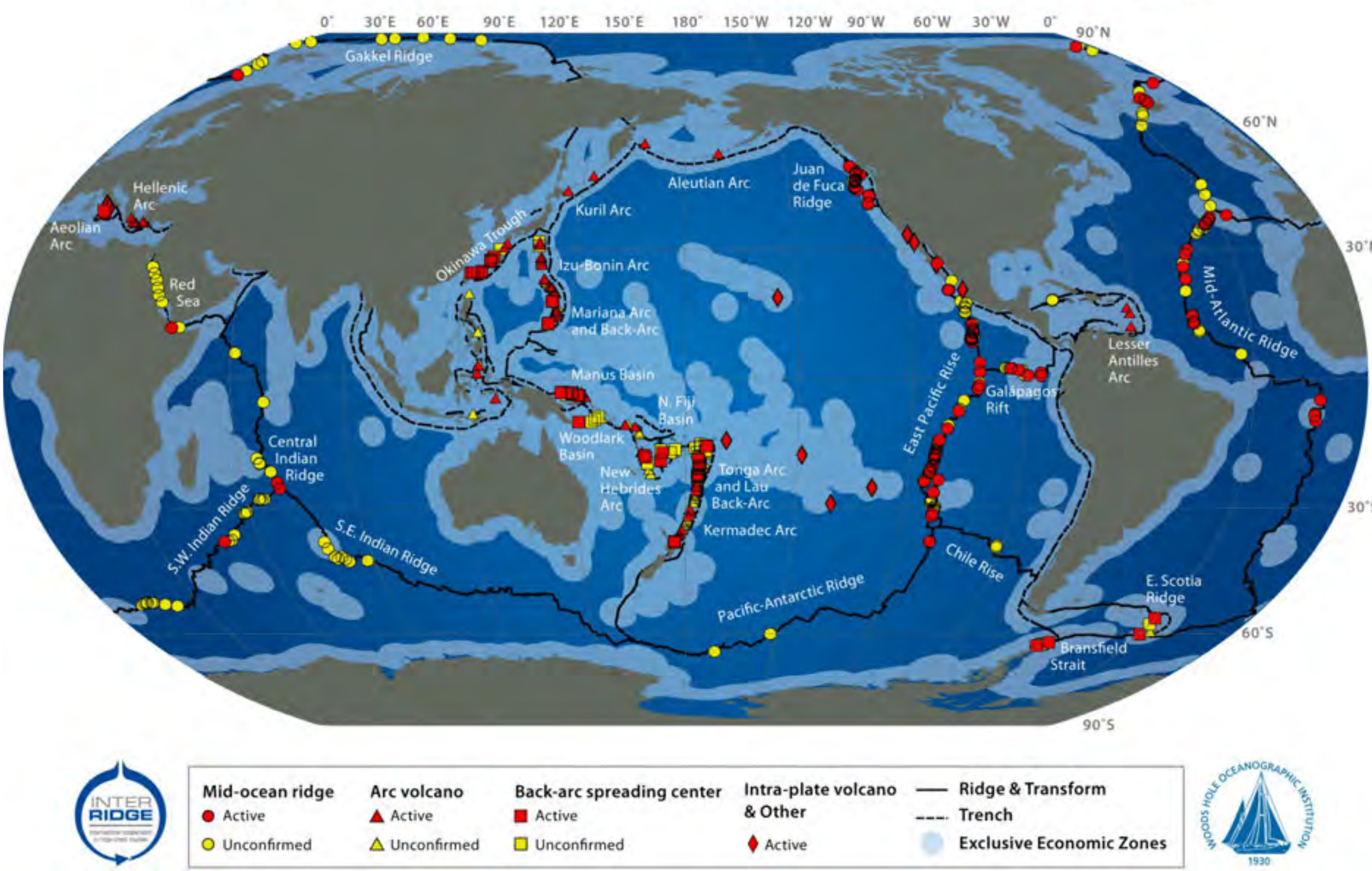
Global Distribution of Hydrothermal Vent Fields



INTERRIDGE

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

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64,000 km of oceanic spreading centers
25,000 km of volcanic arc systems

Rare metals in Seafloor Massive Sulfides as Potential Byproducts of <u>Copper</u> or <u>Zinc</u> Mining

Gold
Silver

Antimony
Arsenic
Cadmium
Gallium
Germanium
Indium
Selenium

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Rare Earth Element-rich Muds

nature geoscience

LETTERS

PUBLISHED ONLINE: 3 JULY 2011 | DOI: 10.1038/NGEO1185

Deep-sea mud in the Pacific Ocean as a potential resource for rare-earth elements

Yasuhiro Kato[1]*, Koichiro Fujinaga[1], Kentaro Nakamura[2], Yutaro Takaya[1], Kenichi Kitamura[1], Junichiro Ohta[1], Ryuichi Toda[1], Takuya Nakashima[1] and Hikaru Iwamori[3]

Is there an economic resource potential?

Not unlikely!

Is there an strategic resource potential?

Possibly!

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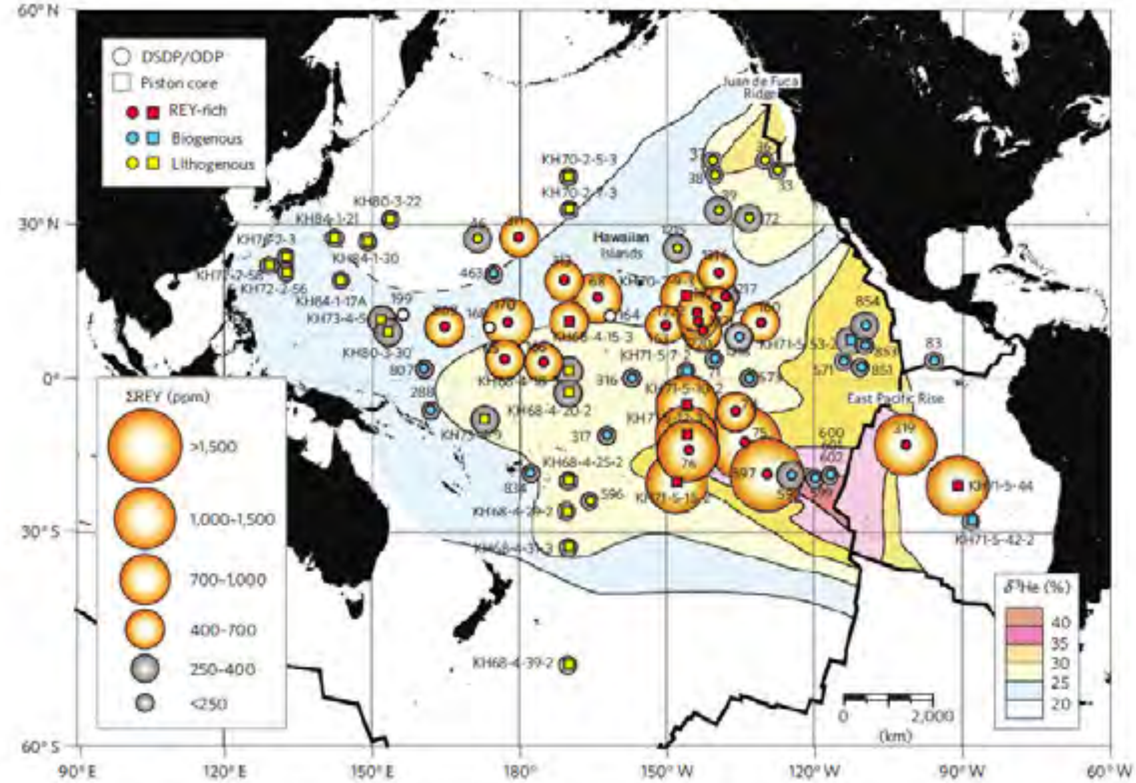


Rare earth element-rich mud found in Japanese EEZ

Similar REE-rich muds may be found in the US Wake I. EEZ and eastern part of CNMI EEZ

USGS

Large rare earth deposits discovered / Valuable cache found within nation's EEZ

The Yomiuri Shimbun

Large and rich rare earth deposits, equaling at least 220 times the country's annual consumption, have been discovered near Minami-Torishima island in the Ogasawara Islands, a research team has said.

Exclusive economic zone
Red dots indicate locations where rare earth minerals were found.

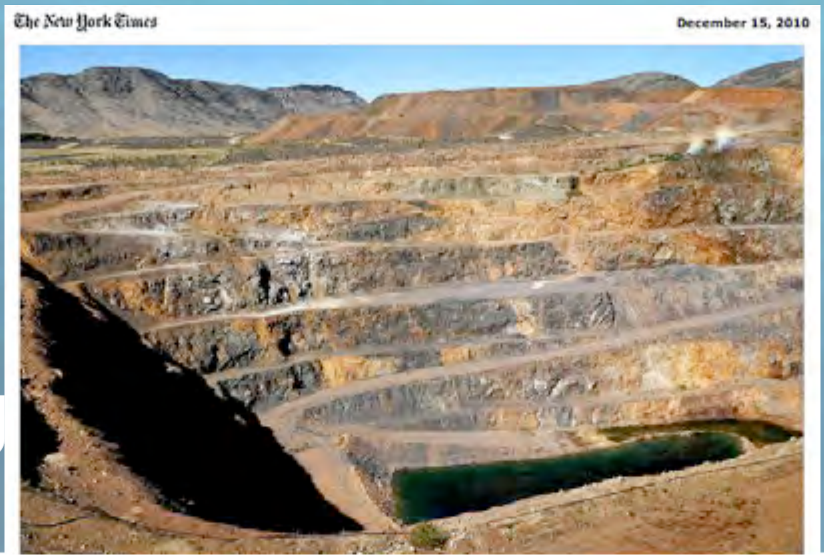
This is the first time large rare earth deposits have been discovered in the country's exclusive economic zone. The team led by Prof. Yasuhiro Kato of the University of Tokyo found the deposits after analyzing samples of seafloor sediment taken from a depth of 5,600 meters near Minami-Torishima.

Mud containing a large deposit of rare earth elements was nearly 10 meters deep, judging from samples taken about 300 kilometers southwest of the island.

The team also confirmed large rare earth deposits in mud about 500 kilometers north and about 500 kilometers southeast of the spot. The southeast location is outside the EEZ.

Unique characteristics of marine mines

- Marine-based mine sites have no roads, seafloor ore transport systems buildings, or other infrastructure
- No overburden to remove, which on land can be 75% of material moved
- High grades: less ore needed to provide the same amount of metal
- Three or more metals can be obtained at one mine site
- Smaller deposits can be mined because of moveable mining platform
- No indigenous populations to displace or personnel in harms way at the mine site

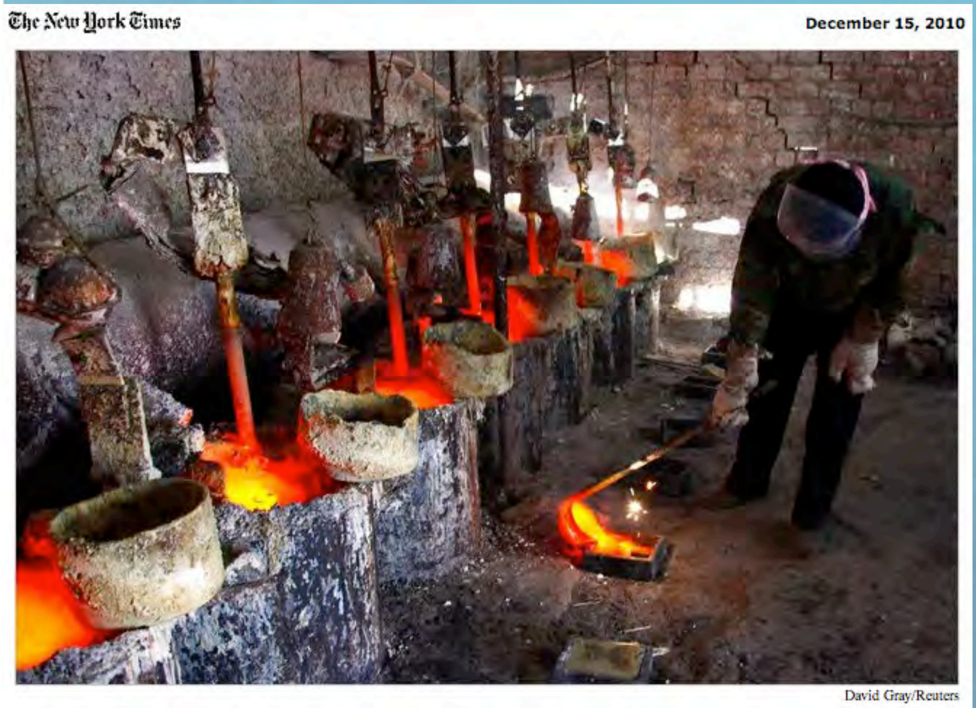


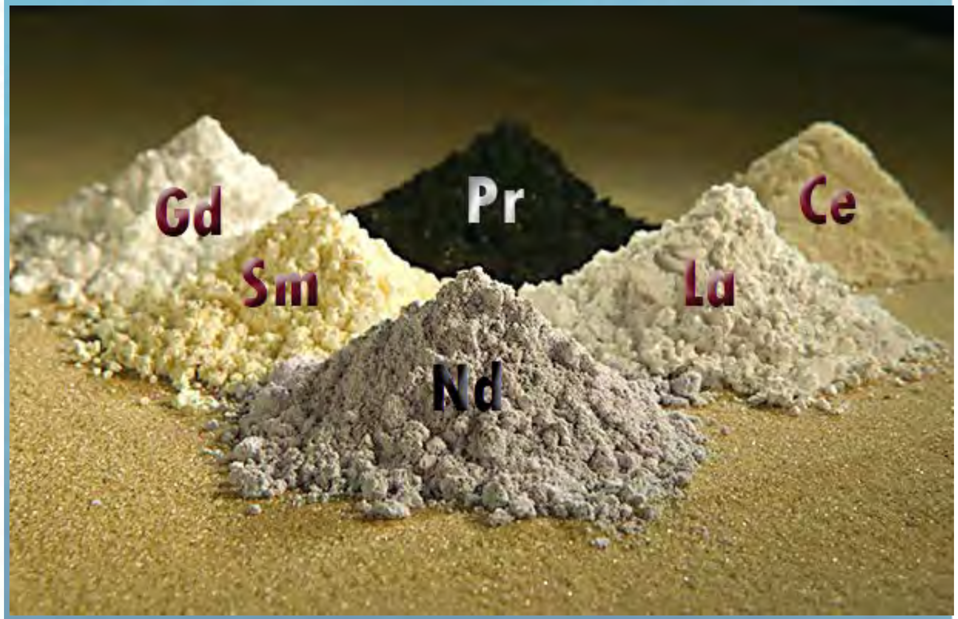
Unique Characteristic for Extractive Metallurgy

Land-based ores require extensive processing

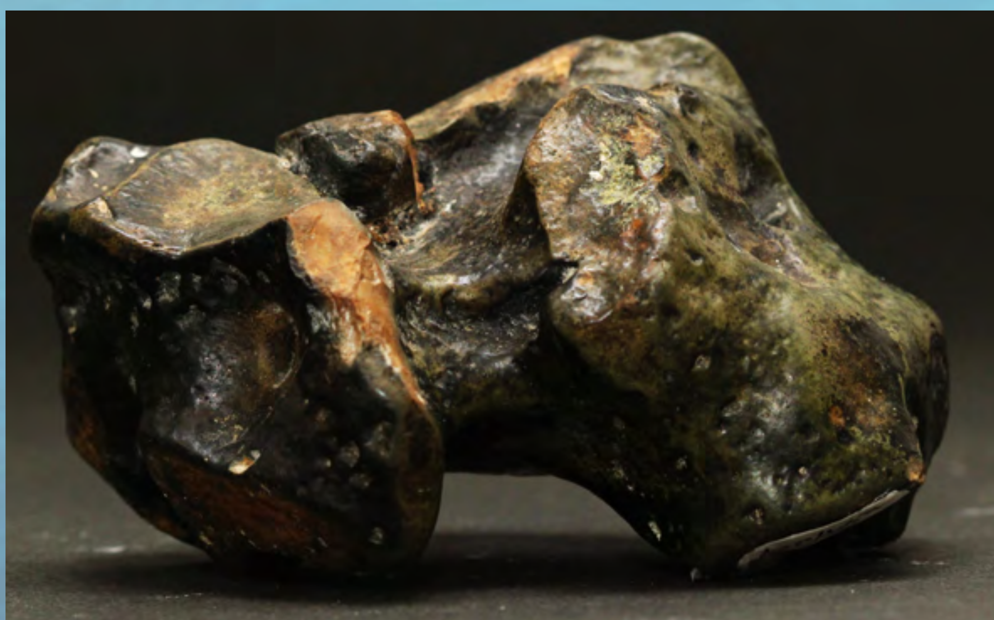
Marine iron and manganese oxides can be dissolved with simple HCl leach putting all sorbed critical and rare metals into solution which can then be selectively removed

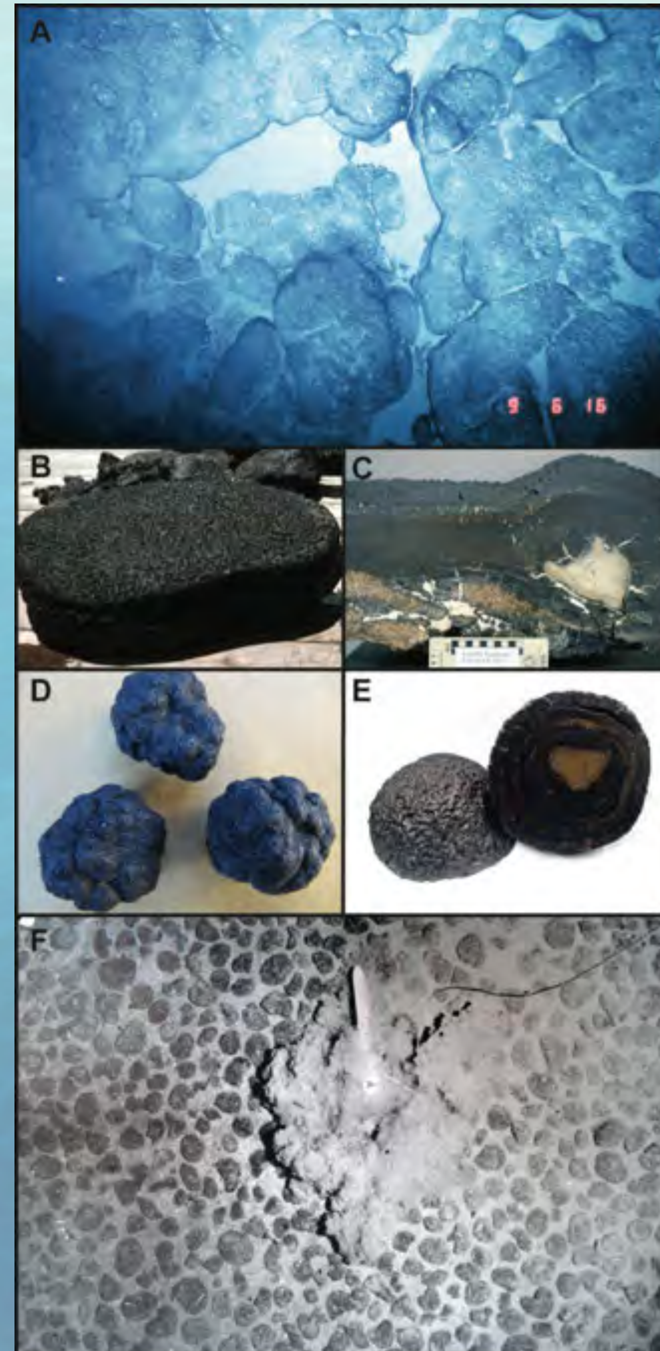
Marine sulfides & phosphorites can be processed in existing plants





Rare Earth Elements: Comparison of Ferromanganese crusts and nodules, and Phosphoritite





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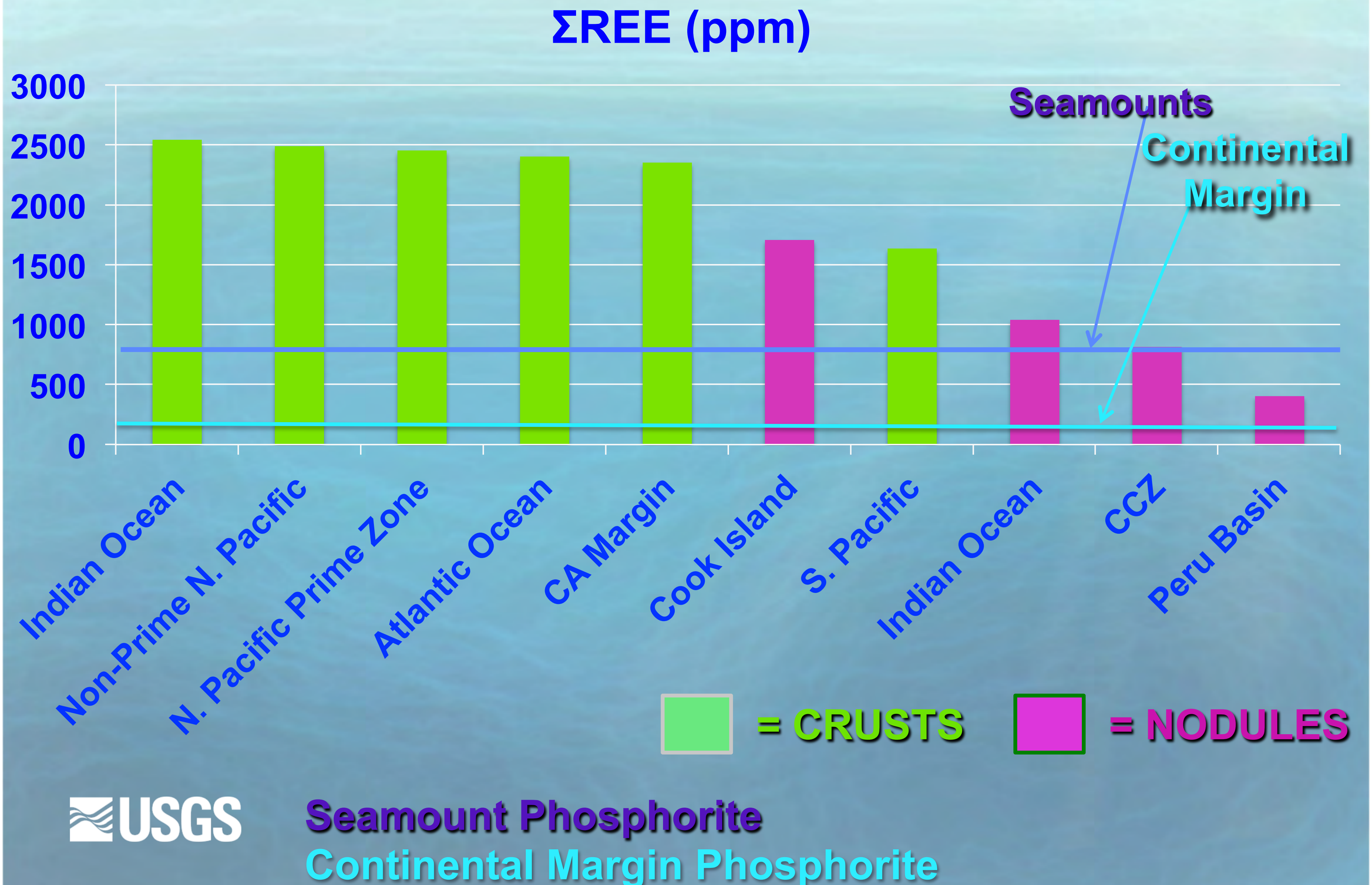
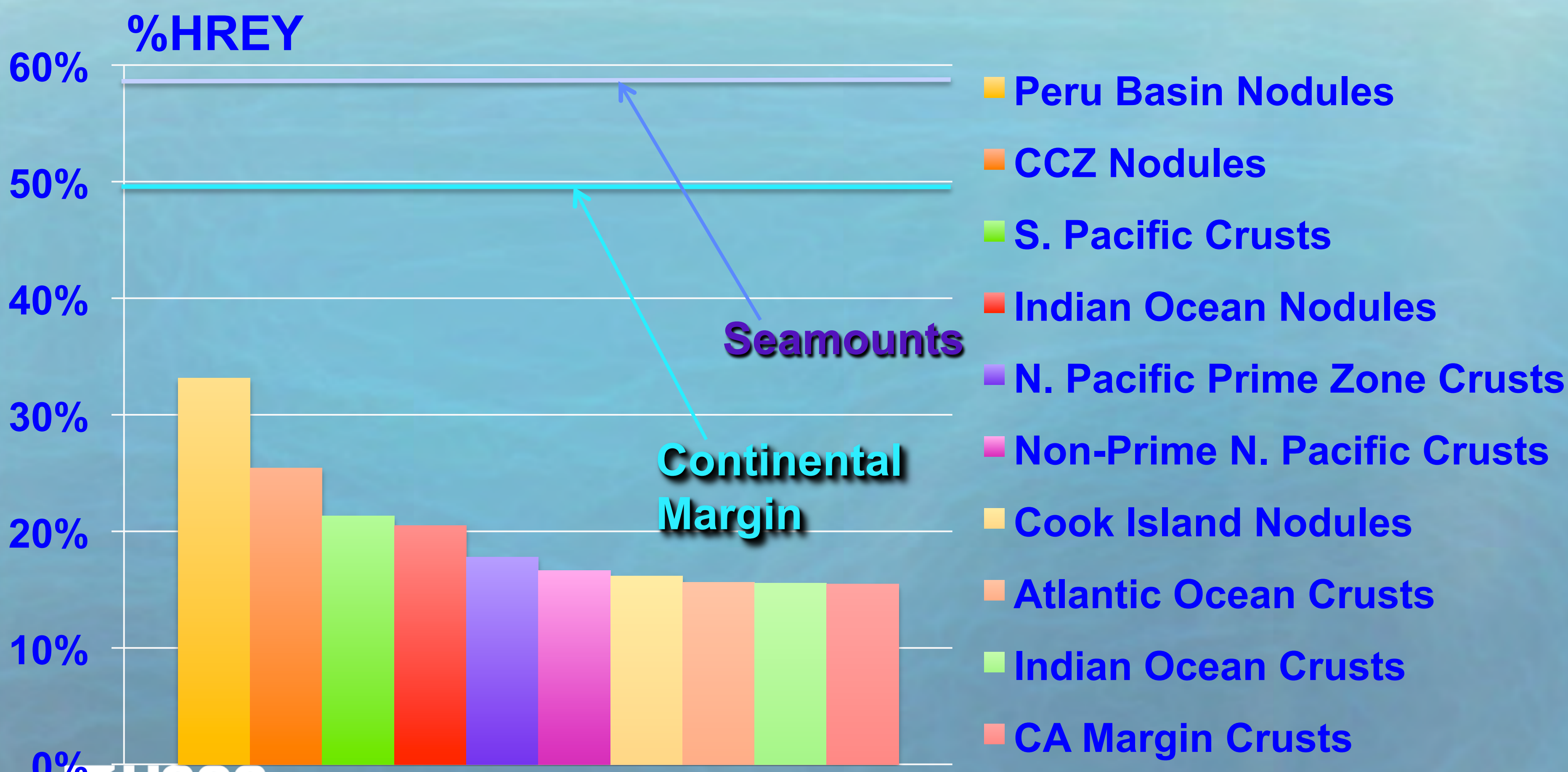
Total REE in Fe-Mn crusts, nodules, and phosphorite (ppm)



Heavy REE Complement of the total REE

Mountain Pass and Bayan Obo mines contain <1% HREY



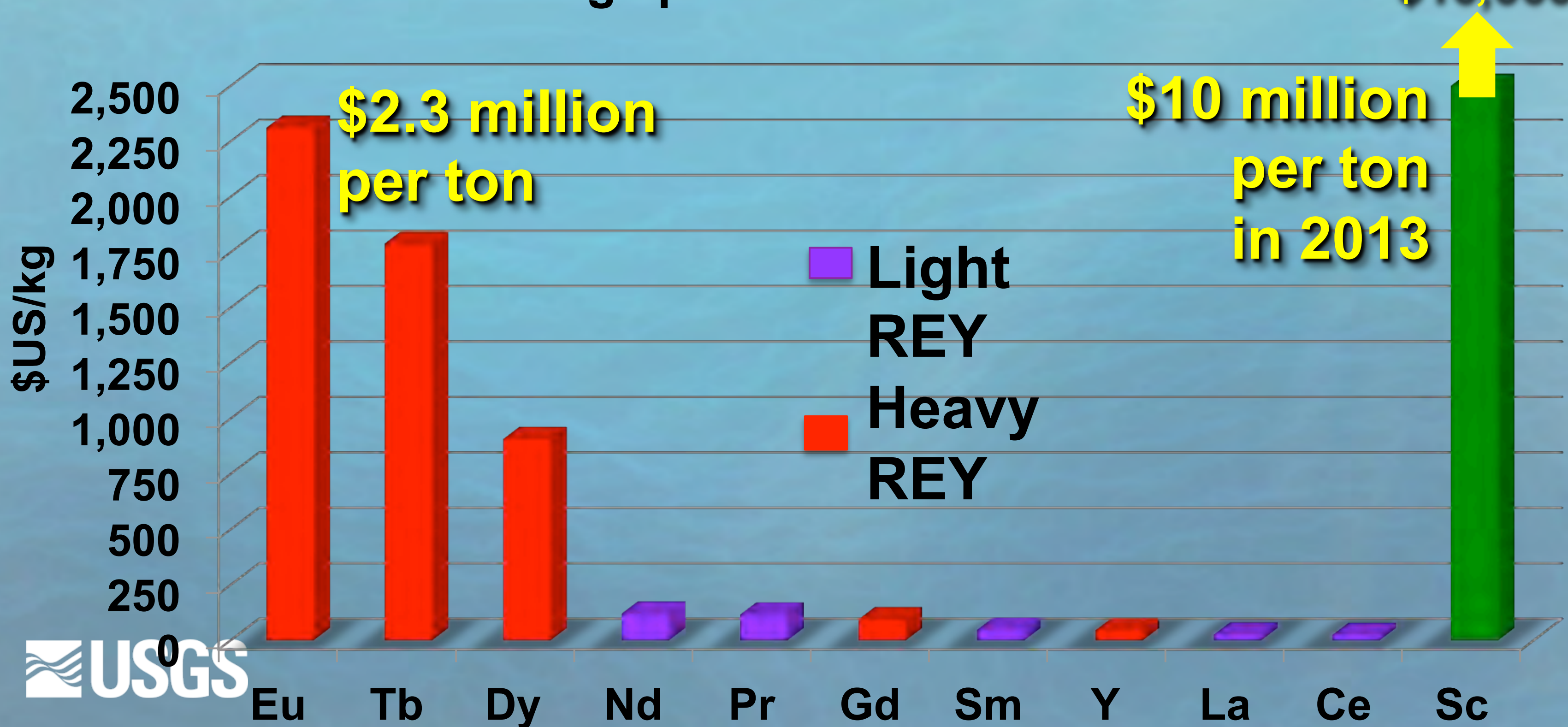
Light versus Heavy REY

Large land-based REY deposits average less than 1% HREY

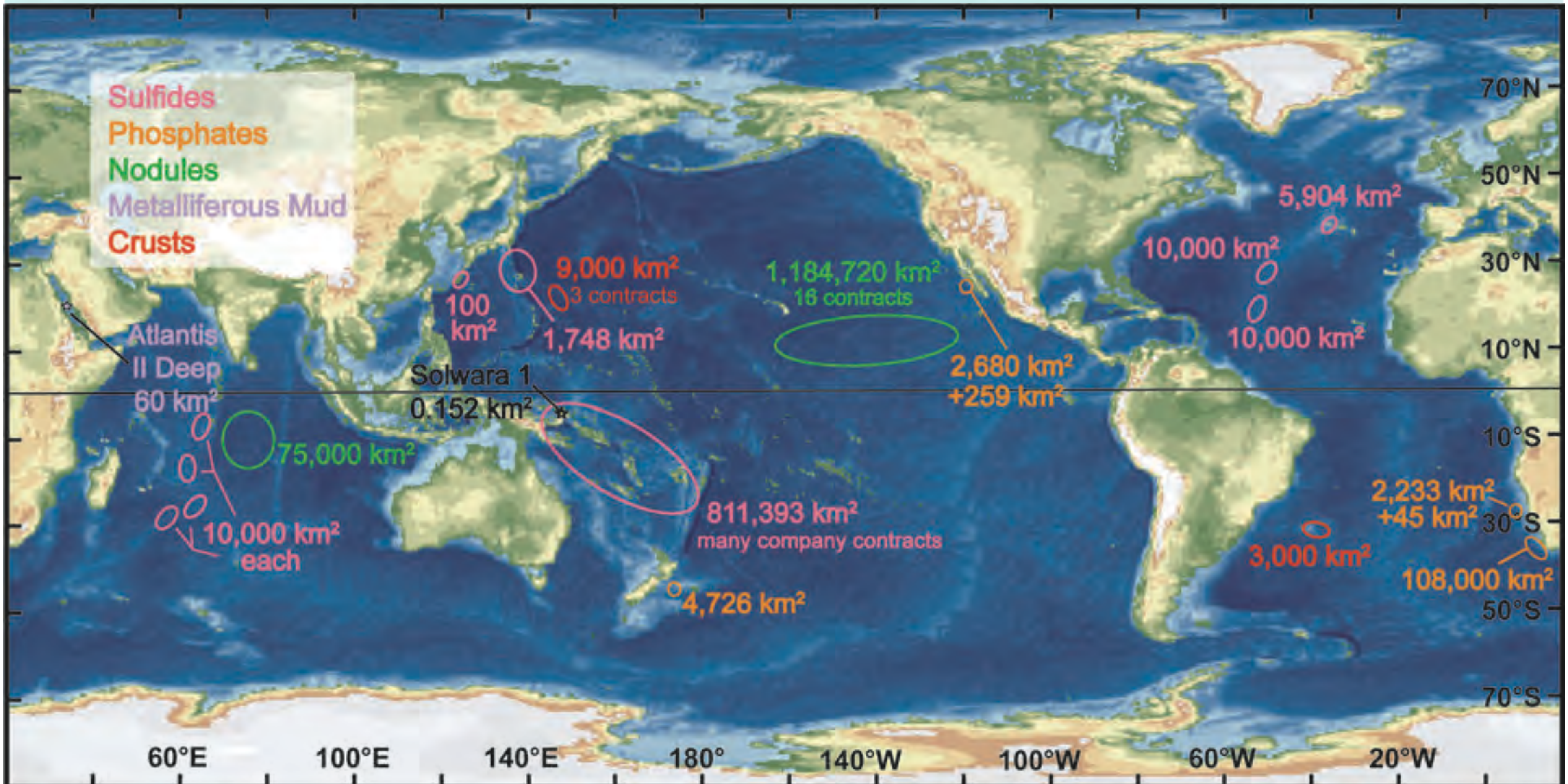
% HREY in Marine Deposits

	PCZ Crusts	Crusts Arctic	Cook Is. Nods.	CCZ Nodules
% HREY	18%	23%	16%	26%

Average price from 2011-2013



Contracts for Marine Minerals <u>Exploration</u> Total 2,300,000 km²



(Modified from Hein et al., 2013)

Total contract area is the size of the land area of Greenland

USGS **Approximately 50% is in EEZs and 50% The Area**

10 States & State Agencies with 20 deep-ocean minerals exploration contracts with ISA

X = APPROVED

State/State Agency	Nodules	Sulfides	Crusts
China	XX	X	X
France	X	X	
Germany	X	X	
India	X	X	
Japan	X		X
Korea	X	X	
Russia	X	X	X
[a]Inter-Ocean Metals	X		
Cook Islands	X		
Brazil			X

USGS

[a]Bulgaria, Cuba, Czech Republic, Poland, Russia, and Slovak Republic

Biological Ecosystem Structure

(Photo Credit: NOAA, Crinoids, deep-sea corals, sea stars, bryozoans, anemone; Davidson Seamount, 2668 m)

ISSUES

- Colonization tactics, dispersal
- Species diversity
- Reliance on mineral deposit itself
- Endemism
- Global marine protected areas

USGS

Priority US EEZ Area for Ferromanganese Crusts

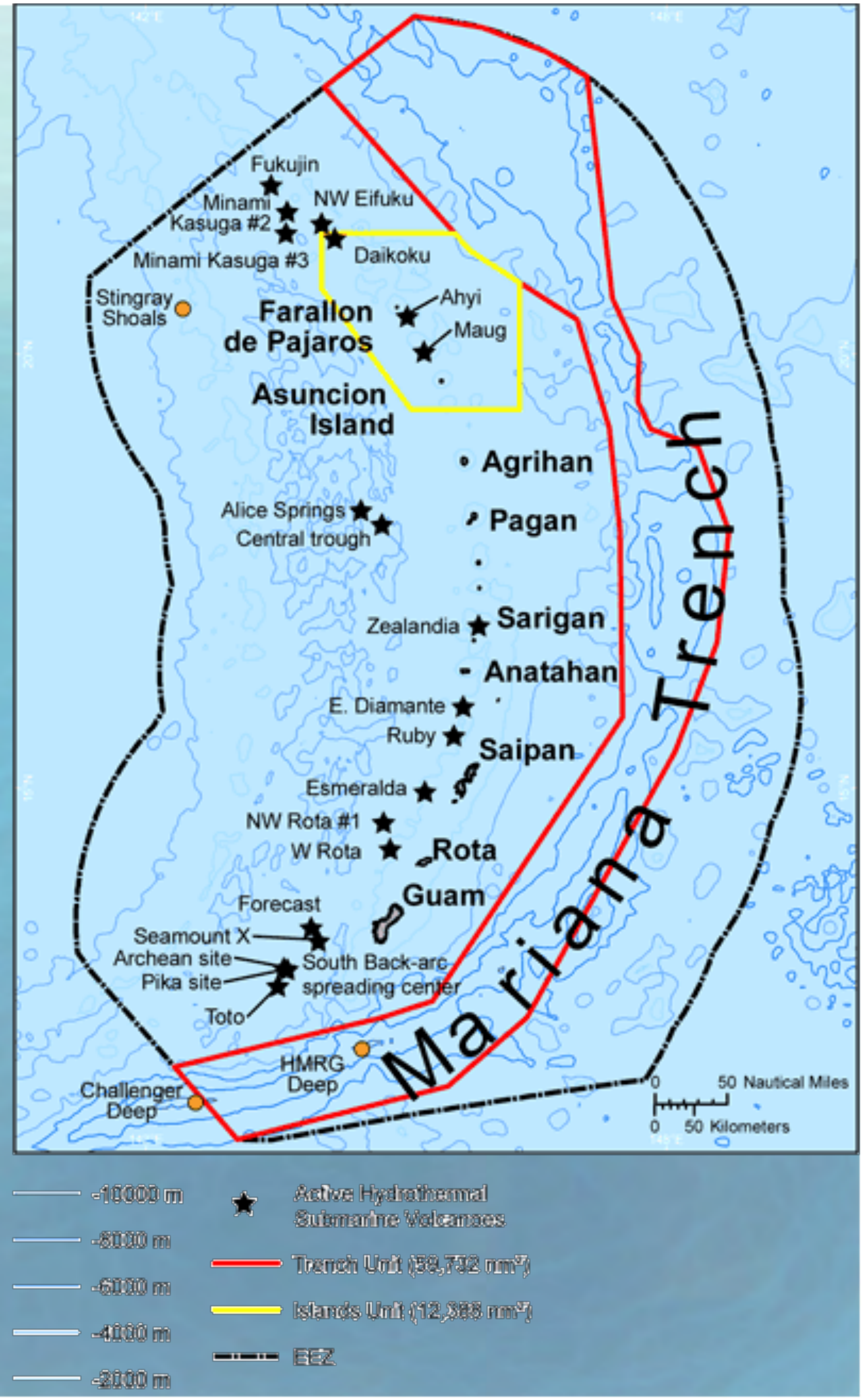
The US EEZ (black dashed) and outline of Mariana Trench Marine National Monument (Red, yellow, and stars)

The area east of the Mariana Trench is not in the MNM and is the most prospective area in the global ocean for thick ferromanganese crusts rich in rare metals and rare earth elements, which are likely to occur on the huge seamounts and ridges

The abyssal plain in that area is also prospective for rare earth element-rich muds

Largely Unexplored US EEZ

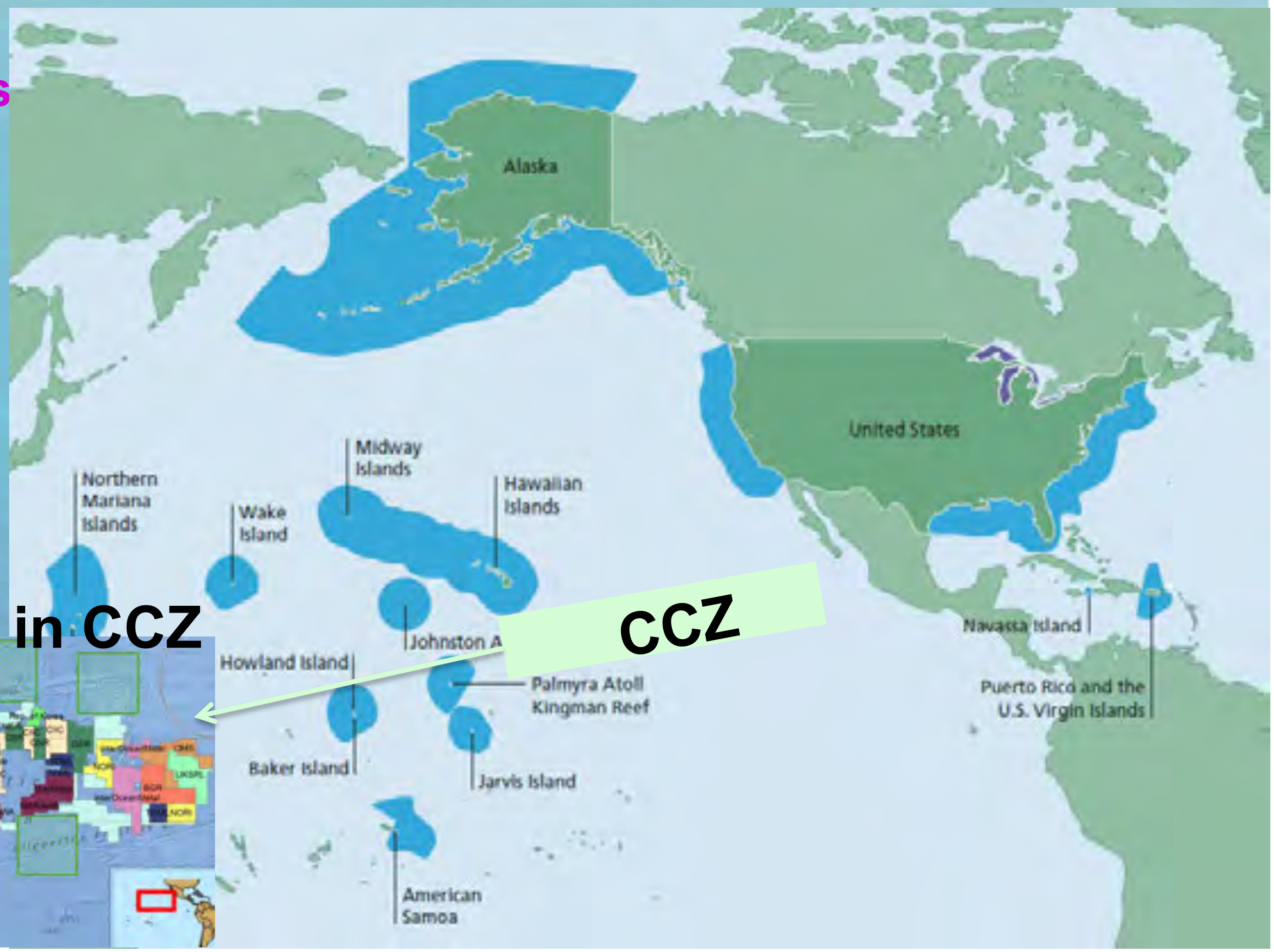
USGS



Priority US EEZ Area for Manganese Nodules

The US EEZs of Johnston Atoll, Kingman-Palmyra Is., and Jarvis I. fall near the western end of the Clarion-Clipperton (CCZ) prime nodule area, where there are 16 exploration contracts through the ISA

These three US EEZs are Unexplored for manganese nodules and their resource potential



16 contract areas in CCZ

Priority US EEZ Area for Seafloor Massive Sulfides

The US EEZs of Alaska (Aleutian Islands), CNMI (active volcanic arc and back-arc trough), NE Pacific ridges, and Caribbean arc fall wholly within or in part within the US EEZ. The CNMI arc and NE Pacific ridges have been well explored although additional work is needed. The Mariana back-arc trough is partly explored and needs further exploration. Hydrothermal systems in the Aleutian volcanic arc are unexplored and warrant exploration.

The eastern Aleutian arc is where seduction is occurring, unlike the western arc which is a strike-slip margin. The eastern arc should host off-shore hydrothermal systems (stars)

USGS

Preliminary Shipboard Equipment and Operations

	SMS	FMC	MN
Phase 1			
Multibeam bathymetry (MB), geophysics	X	X	X
MB back-scatter acoustic imagery	X	X	
Tow-yo CTD and sensor array, plume mapping	X		
CTD, oxygen sensor, water column	X	X	
Dredging		X	
Box core and grab sampling			X
ROV sampling, imagery	X	X	
Phase 2			
ROV sampling, imagery	X	X	X
ROV hydrothermal fluid sampling	X		
AUV mapping, imagery, other sensors	X	X	X
Environmental sampling, currents	X	X	X

USGS

SMS-Seafloor massive sulfides; FMC-Ferromanganese Crusts; MN-Manganese nodules

USGS Priorities for OE

Continued collaborative campaigns on Ecosystem Structure & Function in Shelf Edge/Slope Environments (U.S. South Atlantic)

Post-ECS Priorities

1. Subduction Zone Geohazards (Cascadia, Alaska …. Caribbean)
2. Arctic – Gas Hydrate/Methane Systems focus to understand Arctic resources and ecosystems, and

   Marine Minerals – foundation for resource assessment and understanding associated ecosystems

USGS